SAARC Workshop on

LANDSLIDE Risk Management in South Asia

11-12 May 2010, Thimpu, Bhutan

SAARC

Organised by

SAARC Disaster Management Centre, New Delhi

In collaboration with

Ministry of Home and Cultural Affairs, Royal Government of Bhutan

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Ministry of Home & Cultural Affairs
Royal Government of Bhutan
Tashichho Dzong, Thimphu

བློན་པོ།
MINISTER

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Message

It was indeed an honour for Bhutan to host the XVIth SAARC Summit, the Silver Jubilee year of SAARC, from 24-29 April, 2010, in Thimphu, Bhutan. The main theme of the Summit was "Climate Change", a most relevant topic for the SAARC regional countries.

At the Summit, the Heads of SAARC Member Countries noted with deep concern, the unprecedented challenges posed by Climate Change in South Asia and underlined the grave fact that the region is increasingly afflicted by a number of climate change related disasters. Climate Change is having and will have a profound effect on the environment and on people's lives.

Recurring disasters, including landslides, pose a major development challenge for all SAARC countries. It is therefore timely and most appropriate to conduct this very important SAARC regional workshop on Landslide Risk Management in South Asia, in Thimphu, Bhutan.

I strongly believe that our region needs to prepare effectively to adapt to the effects of climate change and secure the lives and livelihood of our people. We need to systematically formulate and implement effective and coordinated strategies to mitigate and respond to various disasters within our countries and within the region.

I am pleased to note that the present workshop will deliberate on the formulation of a regional road map for Landslide Risk Management in the region. I am confident that with able guidance from the SAARC Disaster Management Center (SDMC) and valuable contributions from experts in the region, the workshop will meet with every success.

I wish all participants meaningful and productive discussions.

Tashi Delek!

(Minjur Dorji)

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དྲུང་ཆེན
SECRETARY

Message

South Asia is one of the most disaster-prone regions of the world today. Two thirds of all natural disasters in South Asia are climate induced and climate related.

Bhutan, as a small, landlocked country with a fragile and mountainous ecosystem, is seriously threatened by climate change. Even a two-degree rise is projected to cause devastating impacts on our mountain glaciers and hydrological systems, and the signs are already visible with the rapid melting of our glaciers. I am sure that the scenario in other Member States would be similarly grim.

Among the many hazards that we encounter in South Asia, landslide is one of them, and its severity and frequency is climate related, making it an impending threat to our region's entire eco-system.

This workshop organized by the SAARC Disaster Management Center in collaboration with the Department of Disaster Management, Ministry of Home and Cultural Affairs, with its focus on landslides is therefore timely, and has presented an opportunity for member states to share experiences and exchange best practices.

I am hopeful that within the two days, representatives of all member States have had fruitful discussions and shared strategies, policies and programmes to prevent and mitigate landslides and used this forum as a platform for knowledge sharing.

On behalf of the Ministry of Home and Cultural Affairs and the Royal Government of Bhutan, I would like to thank the Director and the staff of the SAARC Disaster Management Center and all the participants for their invaluable contributions to the workshop.

I wish all of you success in all your future endeavours.

Thank You and Tashi Delek!!

(Penden Wangchuk)

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SAARC DISASTER MANAGEMENT CENTRE, NEW DELHI

P. G. Dhar Chakrabarti
Director

11 May 2010

Landslide is one of the neglected disasters in South Asia in as much as these usually take place in isolated and dispersed locations and do not create the big headlines that earthquake, flood or cyclone does. Therefore, landslides have not engaged the kind of attention among the policy makers at the national, and much less at the regional level, as it deserves. The cumulative effects of landslides, however, in terms of loss of lives, property and infrastructure have been quite substantial. There have been instances when many rural settlements in the hilly slopes have gone in complete oblivion and many rural and urban settlements have been very severely affected due to landslides. Disruption of road network and communication systems have been more common, creating serious impact on life and economy.

Seven out of eight countries of South Asia are affected by landslides due to a variety of factors, both natural and manmade. Among the natural factors, geology as well as hydro-meteorology has played their parts. Earthquakes of even lesser magnitudes have triggered massive movements in hilly slopes. Incessant rainfall has been a more common factor for causing landslides. Even cyclonic storms and resulting precipitation have resulted in landslides in the hills, as the cyclone Aila had demonstrated last year. The climate change and its impact on glacial melts and changing rainfall pattern have the potentiality of increasing both the frequency and intensity of landslides. Large scale of deforestation has definitely increased the incidence of landslides just as unplanned settlements in hilly slopes intensified the impacts of such disasters.

In order to discuss all these and related issues and develop a common Road Map for Landslide Risk Mitigation in the South Asia region, for a short, medium and long time frame, senior policy makers and experts from the SAARC countries shall meet for two days in Thimpu, Bhutan. SAARC Disaster Management Centre places its gratitude to the Ministry of Home and Cultural Affairs of the Royal Government for hosting this workshop.

We are happy to bring out this publication to facilitate serious discussion in this workshop.

(P. G. Dhar Chakrabarti)

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Background Paper

SAARC Disaster Management centre, New Delhi

Executive Summary

Of the many concerns shared by the SAARC countries in the area of disaster management, Landslide Risk Management deserves to be placed high on its priority agenda for many compelling reasons. It is a part of their global commitment and obligation to posterity. The world looks up to the SAARC countries for direction and leadership in this area because no other region is directly exposed to such a bewildering variety of landslides and other mass movements. SAARC carries a remarkable weight of experience with the Himalayas, the youngest, largest, highest, densely populated, and the most dominating mountain system in the world. The Himalayas, now under severe environmental strain, support more than 140 million people directly and another one billion people downstream, living under perennial threat of landslides. It is worthy of note that a landslide follows the same natural laws regardless of the country and its place of occurrence. It knows no territorial boundaries. And the best way to

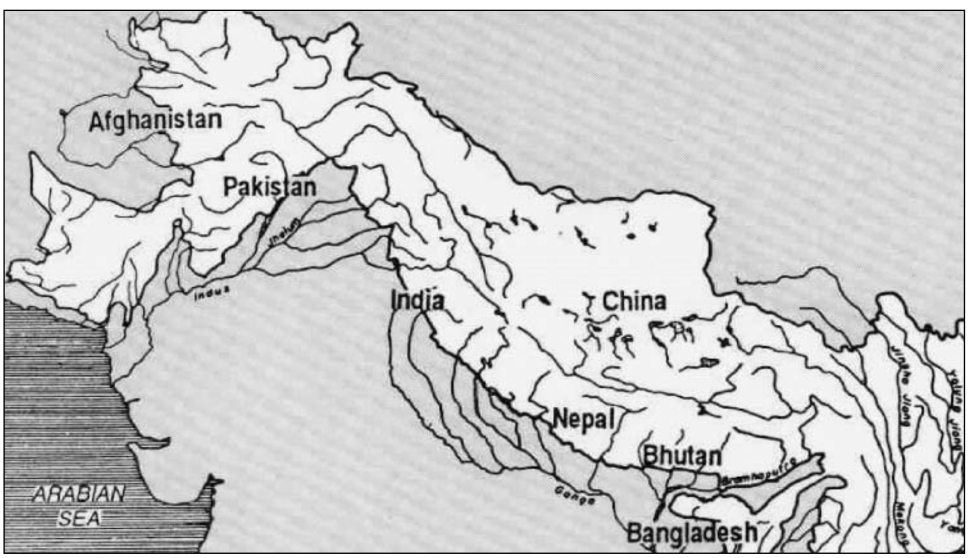

Figure 1: Six of the eight SAARC countries are blessed with rich experience in managing landslides in the Hindu Kush Hamalayas. (Source: ICIMOD, April 1995)

manage landslide risks is to act together with shared vision and common strategy, simultaneously as the national capacities are built. The daunting challenge of landslide risk management which currently appears to be beyond the capacity of any individual SAARC country to meet seems well within their collective grasp.

The paper, inter alia, presents assembly of thoughts, ideas and proposals to serve as a framework for discussion at the proposed SAARC workshop. Based on the snapshots of landslide scenario in SAARC countries, it identifies areas of shared interest and puts forward thoughts for regional cooperation. Topics such as the frame work for landslide management, multi-hazard zonation, integration of landslide management with development planning and main areas of capacity building are discussed.

Spectacular landslides frequently show up as eyesores in parts of Afghanistan, Bangladesh, Bhutan, India, Nepal and Pakistan all associated with Hindu Kush Himalayas, Figure 1. The remaining two SAARC countries, namely, Sri Lanka and Maldives too have their own concerns and contributions in this area. Unlike the landslides in the fragile Himalaya, the landslides of Sri Lanka ravage geologically one of the most ancient and rugged mountain ranges in its central highlands. Whereas Maldives has a lot to offer in terms of the science of sea-coast instability and the technology of coastal slope protection, India and Bangladesh too face the grave consequences of coastal / sub-marine landslides in the vicinity of Indian ocean. An inventory of some recent landslides in South Asia is given in Annexure 1.

Cross fertilization of ideas on effective landslide management is necessary to create a sharper focus and concerted action seems essential to create a critical mass of effort to hasten the process. SAARC region has a golden chance to take advantage of global initiatives and leap frog into landslide management capacities and strategies which otherwise elude them for quite some time. The 2006 Tokyo Action Plan on Landslides- the outcome of the roundtable meeting organized by the United Nations University in Tokyo on 20 January 2006 may provide added stimulus to the deliberations. The Tokyo Action Plan aimed at Strengthening Research and Learning for Global Landslide Risk Management. Later the International Consortium on Landslides along with various international partners and UN bodies organized the first meeting of World Landslide Forum in Tokyo in November 2008. A unified declaration was made during this meeting which once again highlighted the need for focused and concerted efforts at international levels for mitigating the impacts of landslides. During the deliberation, it emerged that the SAARC countries are among the worst landslide affected countries. Hence, the time is ripe for the SAARC programme on Landslide Risk Management to harness the benefits of global thought process and connectivity.

This background paper benefits from the multitude of inputs and studies from SAARC countries viewed through the prism of the global state-of-the-art. It provides a snapshot of landslides in the SAARC region and churns the problems vigorously to throwup high priority common concerns so as to set the tone for the workshop. It should also be regarded as an opportunity to gauge the mounting new threats posed by Climate Change, Glacial Lake Outburst Floods and Earthquake Induced Landslides

The core issues connected with the multifaceted aspects of landslide risk management are highlighted in the paper. These include landslide hazard, vulnerability and risk assessment; approach to landslide risk management and the related framework. While underscoring the urgency to develop Landslide Disaster Management Plans, emphasis is laid on ensuring the safety of housing and human settlements as well as the safety of strategic installations, cultural heritage and lifeline structures.

Main areas requiring capacity building are discussed with particular reference to considerations such as scientific investigation of landslides, strengthening of relevant building codes, promotion of the observational method of design and construction, early warning against landslides, landslide education and training, public awareness and community leadership development and fostering, promoting and sustaining the culture of quick response.

Besides above, the paper spotlights thrust areas for research and development, landslide knowledge management and operational and administrative issues in landslide risk management. Importance of techno-legal regime, fiscal incentives and Insurance is also highlighted.

The Context and the Aim of the Workshop

A vibrant SAARC Road Map for effective Landslide Risk Management in the South Asia is aim of the workshop. It is to be drawn with the ink of the shared vision and collective wisdom of the member States. The implementation of the road map is to be driven by a strategy fashioned to achieve synergistic action with leveraged capacities, pooled resources and political will.

For the proposed SAARC road map on landslide risk management to have a down-to-earth connection with the ground realities and the expected outputs, the first logical step is to take stock of the nature of the landslide problems in their varied dimension and fully understand the likely risk scenarios on one hand, and the national capacities to manage landslides on the other hand.

There are three things very special about this workshop. First, unlike other discussion meetings, it will focus expressly on a few important questions critical to Landslide Risk Reduction. Second, the event will be powered by the synergy of united action by the SAARC countries, at a time they are already fortified by their respective disaster management policies and strategies. Thirdly, it will mark the visionary response of the SAARC countries to the Tokyo Action Plan on Landslide Risk Reduction 2006 and to the Hyogo Framework of Action (2005-2015) to which SAARC countries stand committed.

Tokyo Declaration 2006 led to establishment of an International Programme on Landslides. We may aim at establishment of a SAARC Programme on Landslides. Tokyo Declaration 2008 created several Global Centres of Excellence on Landslides in different parts of the world. We may aim at creating dedicated SAARC teams on Landslide Studies, and eventually a strong SAARC Centre. The other recommendations made at the meeting also seem to resonate with the issues we may like to flag. We need to give the highest attention to forging of landslide mitigation strategies with focus on landslide education, landslide hazard mapping as a component of multi-hazard mapping, vulnerability and risk assessments, study of catastrophic landslides, monitoring and early warning against landslides, emergency preparedness, training and capacity building of all the stakeholders.

A Snapshot of Landslides in the SAARC Region

Landslides affect seven of the SAARC countries, namely, Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka. The eighth country, Maldives, offers great experience in protection of slopes against sea erosion.

Afghanistan

Afghanistan is a land locked country of diverse topography dominated by the Hindu Kush, the western most extension of Karakoram mountains and the Himalayas, and is spread over an area of 650 000 km^2. Hindu Kush highlands rise from the plains to about 5100m beyond which rest the northern plains. Most of the land (approximately 63 percent) is mountainous. The Hindu Kush peaks rise in heights toward north east Afghanistan, to around 7000m in the high altitude Wakhan Corridor, where Pamir and Karakoram mountains meet. Many passes cut through the Hindu Kush Mountains. Of the eleven geographical zones in the country, the first six zones, namely, the Wakhan Corridor, the Badakhshan, the central mountains, the eastern mountains, the northern mountains and foothills, and the southern mountains and foot hills belong to Hindu Kush mountain system.

The climate of Afghanistan is continental in nature; known by hot summers and cold winters Afghanistan is semi-arid or arid with low rainfall. Infact most of Afghanistan is influenced by weather fronts from the Mediterranean, with low orders of rainfall. The eastern part of the country, being on the margin of the monsoon system, attracts upto 1200mm of rainfall in summer months. Amu Darya is the major river of Afghanistan with origin in the Pamirs, flowing along the northern border, traversing through large areas of central Asia, and eventually drying up before it reaches Aral Sea. The Helmand thriving on snow melt from the southern slopes of Hindu Kush is the longest river entirely within Afghanistan. The Kabul River system traverses the Jalalabad Gorge to join the Indus River in Pakistan.

Earthquakes and landslides are frequent in northern and north-eastern parts of Afghanistan, such as the Badakshan's Hindukush and Pamir mountain ranges. It is located in the tectonically active southern part of the Eurasian plate. The distribution of earthquake epicenters in Afghanistan reveals that the northern and eastern parts of the country are more vulnerable to earthquakes than southern Afghanistan that lies on the undeformed Eurasian plate.[1] It is important to register the shared interest of Afghanistan in safety against earthquake induced landslides. Afghanistan has a history of such slides. When the earthquake of magnitude 7.2 struck Afghanistan, a huge landslide occurred and buried nearly 60-100 homes in Darun-i-Zao village. The landslide killed 60 people and blocked the Samangan River[2] .

Despite the low population density, the province of Badakshan is hugely threatened by avalanches and landslides. According to one report, about 2000 people in Badakhshan live under perennial threat of

1 SAARC Workshop on Earthquake Risk Management in South Asia, 8-9 October 2009, Background Paper, pp4.

2 South Asian Disaster Report 2007, pp108.

landslides and avalanches. The southern edge of the great Himalayan belt in Afghanistan is full of landslides. Rain induced massive floods and landslides have also been reported from central Afghanistan. In July 2007, eight members of a family were killed when a landslide primed by thawing snow ravaged a village in the Takhar district. About the same time, a landslide in the Kunduz province of northern Afghanistan struck a wedding party killing 6 children. On 30 March 2008, a huge landslide struck Bahadur Khan Village of Siah Gard district of Central Afghanistan destroying 30 houses forcing evacuation of a number of families. Another landslide incident killed six people of the Qalae Girdab village in the northern Tahar province.

Landslide episodes and landslide potential of the Bamiyan Valley has captured public imagination the world over. Highly scientific studies of geomorphology and slope instability of Bamiyan valley which is an intra mountainous basin, offers lesson of great profession interest as it is filled with debris feeding from the surrounding slope ranges. Rockfalls have affected the niche of Buddha statues and the explosions in March 2001 brought about huge destruction. According to one report, the eastern Buddha statue is critically threatened.

Afghanistan has huge experience to offer in dealing with rockfalls and landslides. A few of its highways offer a spectacle of landslide problems. Some of the best examples of rockfall come from the Salang Pass roads from the northern border south to Kabul, and the highway from Kabul to Jalalabad which passes through the Kabul River gorge. Snow avalanches are also common on the Salang Pass, the top of which show up at an altitude of 4000m.

Massive slope failures are also known to dam many deep narrow canyons resulting in formation of small lakes. These lakes are unstable and threaten safety when used as a source of water by the local people.

The Government of Afghanistan has established the National Disaster Management Commission to manage its disasters. It is working very closely with the UNDP to unfold a Comprehensive Disaster Risk Reduction Programme (CDRRP). It is seized of the problems of slope degradation and erosion and its increased vulnerability to environmental hazards, thanks to a study published by UNEP in 2003. According to the organograph (at the website http://saarc-sdmc.nic.in), Disaster Mitigation Committee, Disaster Preparedness Committee, National Emergency Committee and National Emergency Operation Centre are operational.

Bangladesh

Bangladesh is located at the foot of Himalayas, bound by India on the west, the north and the north east, Myanmar on the south east and the Bay of Bengal on the south. It covers an area of 14.4 million hectares and is very densely populated.

Bangladesh is known for its alluvial deltaic plain and for its topography of low relief so much so that nearly half the landmass falls in the elevation zone no higher than 8m above the mean sea level. Nevertheless, the hills are found on the northeast, east and south east margins Chittagong area of Bangladesh is badly affected by rain-induced landslides. The high hill ranges, comprising Upper Tertiary Rocks, are steep and dissected with summits rising upto 914m. The valleys and ridges vary in height from 70m to 1000m.

Landslides also occur in the Madhupur and Barind tracts of the Dhaka and Rajshahi districts. The low hill areas consist of sandstones and shales of uppermost Tertiary sequence. Some areas of Chittagong, Comilla and southeastern Sylhet consist of sand stones. Chittagong Hill Tracts which covers 10 % of land area supporting about 1 % of its population. It receives rainfall of the order of 3000mm annually. Rajshahi district is the driest as it receives about 1400mm as against a high of 5000mm in Sylhet. The mean annual rainfall over Bangladesh is 2320mm, the maximum rainfall being 5690mm at Lallakhal in the north east.

Geologically speaking, Bangladesh falls in the Bengal basin which is a part of Indo-Gangetic Trough. The great Himalayan Rivers, upon entering the Himalayan Foredeep, are directed as Indus system flowing south west and Ganga and Brahmaputra system to the east. The three major rivers of Bangladesh are Ganga, Brahmaputra and Meghna.

On 24 June 2000, eight people were killed and hundreds of shanties were wiped away when rain triggered landslides hit the area around the southern part of Chittagong on the Bay of Bengal. The landslide disaster of 11 June 2007 resulted in death of 91 persons of which 59 were children. The rain was so prolonged that mudslides buried houses at the foothills near the Chittagong Cantonment. The worst hit place was Lebubagan area. On 4 July 2009, a landslide occurred near Habiganj town, 250km north east of Dhaka and there are numerous such examples.

Several incidences of landsliding occurred in 2008. A major landslide killed 14 people in Chittagong area in the morning of 18 August 2008. In July 2008, landslides in Cox's Bazar killed 16 people. On 3 July 2008, rain-induced landslides killed 10 persons at Teknaf and Ukhia upzilas.On 6 July; four members of a family were killed at Kalyanpara in Teknaf upzilas.

Slope instability problems also affect the river banks and the coastal belt. Bangladesh offers remarkable examples of river bank failures, for example along river Padma. Slope stability due to river encroachment, and toe erosion of slopes constitute other areas on which Bangladesh has rich experience. Failures due to bursting of the banks of rivers Surma and Khusiara offer notable examples.

Another problem of grave concern to Bangladesh is the alarming rate of slope erosion and loss of land in terms of sediment load. There is a great deal that one can learn from Bangladesh experience in protection of slopes against slope erosion, watershed management and coastal slope protection.

A SAARC study carried out in 1992 underscored the need for geological and geomorphological investigations into the problems of landslides and mass wasting. It recommended landslide hazard mapping by the

Geological Survey of Bangladesh[3]. Importance of anthropogenic factor in landslide hazard mapping assumes a very high significance in the case of Bangladesh because the population density on steep slopes is growing due to scarcity of land.

The Government of Bangladesh has established Ministry of Food and Disaster Management to formulate policies prepare plans, develop national capacities and look after all aspects of disaster mitigation and management. A Disaster Management Bureau has been established under the ministry supported by many committees constituted at various operational levels[4].

Bhutan

Bhutan is located on the southern slopes of the Eastern Himalaya, is about 46,500 sq km in area and it borders Tibet/China in the north and the Indian States of Sikkim in west, Assam in south and Arunachal Pradesh in the east. The Himalayan range at its southern boundary rises suddenly from the North Indian plains starting from altitudes of 200-300m rising to the loftier heights of about 7500m. It can be classified into three physiographic zones, namely, the high Himalaya comprising snowy ranges above 4000m, the inner Himalaya comprising river valleys and steep mountains ranging in height from 2000m-3000m and the Foothills with altitude varying between 200m on the Indian side rising to 2000m towards the north. Soil cover consisting of lithosols and slope wash on the steep slopes is shallow, as would be expected.

Bhutan experiences climates varying from hot and humid subtropical conditions in the south to ice and snow bound Alpine zone in the higher Himalaya. Rainfall varies from less than 500mm in the high Himalaya to about twice as much in the south. The southwest monsoon season which lasts from mid-June to late September drops about three quarters of the annual rainfall with a poor show on the eastern side by the rain shadow effect of the Black Mountain range.

Bhutan is vulnerable to earthquakes, landslides, bursting of glacial lakes, flood and forest fires. Landslides are attributed to the fragile and highly pulverized lithology, steep slopes at elevations ranging from 150mto 8000m, unchecked urbanization and triggers of rain and earthquakes. Placed in Seismic zones IV and V and with the known history of earthquakes including the recent ones in 1980, 1988 and 2003, landslides and glacial lake outbursts constitute perennial threat to Bhutan. According to one study, Bhutan has 667 glaciers, 2674 glacial lakes of which 24 are flagged as potentially dangerous. Eastern and Southern foot hill belt characterized by fractured steep terrain and soil cover on slopes provide ready bed for rain-induced landslides.

3 Regional Study on the causes and consequences of natural disasters and the protection and preservation of Environment published by SAARC Disaster Management Centre, New Delhi.

4 Aminul Kawser Khan (2006) : Management of Natural Disasters. In the book on Management of Disasters in the Developing Countries, published by Centre for Science and Technology of the Non-aligned and Other Developing Countries, New Delhi, India

Major rivers in Bhutan are known to swell causing huge floods and rain induced landslides are known to block national highways. In early August 2000, more than 200 people were killed as several massive landslides struck its several villages over a period of three days. Landslides are known to hamper supply of goods and services to the capital city by blocking the lifeline road from Phuntsholing to Thimphu. This was the first motorable road built in 1961. The road traverses through hill ranges full of slope subsidence, slope erosion, landslides and rockfalls.

Kherbandi Landslide is a very old landslide located at km5 on the highway which has proved problematic for more than two decades, Figure 2.

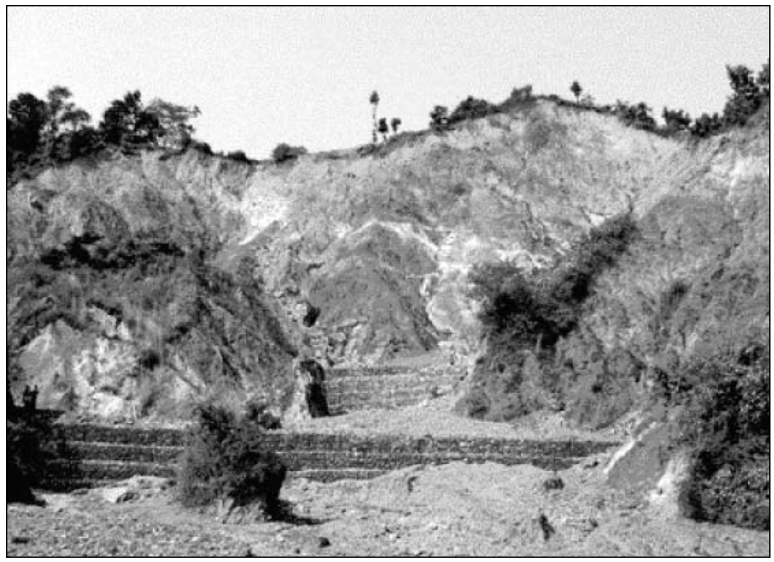

***Figure 2:** A frontal view of Kherbandi Landslide of Bhutan. It is a problem, more than two decades old located at km5 on the highway . (Photo Courtesy: Kishor Kumar)*

The heavy monsoonal rain of the year 2000 destroyed a vast area including hill slopes, the national highway and the nearby police check post. It is precisely the landslides like this which demonstrate that piece-meal implementation of control measures such as toe walls, breast walls and check dams bring no more than momentary relief. Other SAARC countries will have numerous such examples to underscore the importance of a comprehensive approach to landslide control.

The landslide at Sorchen located between km 17 and km18 on the same highway is another trouble spot of recurring nature. The slope degradation and landsliding has been so severe at this location that the associated road alignment which had as many as four hairpin bends (zig) eventually became in operational leaving only one hairpin bend behind. The landslide damage at this location affect 360m stretch of the highway.[5]

Rockfalls and debris slides are as common. It is common to find huge boulders (often compared with the size of an elephant) as for example at km 159 on the Phuntsholing Road. The slope instability problem at Jumbja located at km 41 on the highway is an example of half a century old. Nearly 250m stretch of the road was reported to be under severe threat at the time when slide was investigated by the Central Road Research Institute of India in October 2005.

5 Landslide Investigations on Phuntsholing Thimpu Road in Bhutan, A Report by Central Road Research Institute, New Delhi submitted in October 2005.

Breaches on the highway because of slope failures are also common. One such failure which occurred on the 26 May 2009 at km 143.23[6] is shown in Figure 3. There are landslides that threaten culture monuments. For example, Gumpha (a Buddhist temple) is under threat from landslides.

Figure 3: *Breach of a stretch of highway that occurred on 26 May 2009 at Km 143.23. (Courtesy S. S. Porwal)*

Bhutan also faces severe threat due to Glacial Lake Outburst Floods (GLOF) and consequent debris flows. In the years 1957, 1969 and 1994, GLOF events from Lunana area of north western Bhutan damaged Punakha Dzong. Lugge Tsho glacial Lake had reportedly breached in October 1994. Earlier also, the event of 4 August 1985 which destroyed Langmoche glacial lake eventually wiped out Namche small hydro power plant and 14 bridges among other things[7].

Landslides due to bursting of landslide dams are common throughout the Himalayas and Bhutan is no exception. One such example is formation of landslide dam on the Tsatichhu River which rose to 140m height above the river bottom, in the morning of 10 September 2003. Bhutan also offers examples of deep seated landslides, such as the Sorchen Landslide. Although no national programme of landslide hazard mapping of Bhutan is yet in place, the Department of Geology and Mines and some others have done some work on Landslide Hazard Mapping of certain areas.

Bhutan has several major sectoral laws and policies relating to country's environment. Forest Act enacted in 1969 promises minimum forest cover of 60 percent. This is the best thing that could have happened to reduce landslide risks. When the development programmes progress to take the road communication and electricity to rural areas and improve upon mule tracks and foot path, the Forest Act will act as a shield. It will not be out of place to mention that infrastructure development is important. Department of Works and Housing and Department of Roads are responsible for taking forward the infrastructure projects.

India

Large parts of India, especially the Himalayas, the Northeastern hill ranges, the Western Ghats, the Nilgiris, the Eastern Ghats and the Vindhyas, face the threats of landslides in that order. In the Himalayas alone, one could find landslides of every fame, name and description- big and small, quick and

6 S.S.Porwal, Chief Engineer, Border Roads Organization of India (Personal Communication)

7 ICIMOD Newsletter No 38, Winter 2001/2: Mountain Flash Floods.

Figure 4: *One the most spectacular and most recent landslide in the Nilgiris which destroyed human settlements at the foot of a slope. (Courtesy: Ganapathy)*

creeping, ancient and new. India's northeastern region, Sikkim and Darjeeling in particular, are seen to be bristling with landslide problems of a bewildering variety. There are landslides in the Western Ghats (southern India) along the steep slopes overlooking the Konkan coast. Landslides are also very common in the Nilgiris, characterized by a lateritic cap, which is very sensitive to mass movement. In the avalanche valley of the Nilgiris, majority of landslides do occur in a loose cover of debris consisting of boulders. The major landslides in the Nilgiri hills are the Runnymede landslide, the Glenmore slide, the Conoor slide and the Karadipallam slide. One the most spectacular and most recent landslide in the Nilgiris is shown in Figure 4. Varnunawat landslide (2003) which threatened human settlements at the foot of a slope is one of the better studied landslides in India, Figure 5.

Figure 5: *Varunawat landslide in the Uttarakhand State of India is yet another example of a major landslide which threatened human settlements at the foot of a slope. (Courtesy: Nawani)*

The first state of the art report on Landslides of India came from GSI in 1980. The first landslide Atlas of India was published by Building Materials Technology Promotion Council of the Govt. of India in 2004.

Landslide disasters in India have occurred in the past both as either sudden unexpected first time landslides and as tragedies unleashed by the reactivation of known but neglected landslides. The Malpa rock avalanche tragedy of Uttarakhand which instantly killed 220 people and wiped out the entire village of Malpa on the right bank of river Kali in the Kumaon Himalaya in 1998 was the first time, totally unexpected occurrence. On the other hand, spate of landslides triggered by the Darjeeling floods of 1968 which destroyed vast areas of Sikkim and West Bengal were both- some first time, and some repetitive.

Landslide tragedies in India due to breach of landslide dams are also common. The great Alaknanda Tragedy of July 1970 provides a striking example of death and destruction unleashed by the breach of a landslide dam at its confluence of river Alakhanda with river Patal Ganga.

The Indian landslide scenario is sculptured chiefly by unchecked violence against its mountains, extremes of geo-climatic variations, adverse hydro-geological factors and brutal human intervention, fuelled by non-engineered construction and sky-rocketing population. The landslide belt in the Himalayas more or less match with the earthquake belt and that underscores the importance of the study of earthquake-induced landslides. This aspect of landslide study assumes special significance not just because of the shared concern of the countries of south Asia but because of the urgency to integrate risks due to earthquakes and landslides in hazard assessment and to improve upon the not so efficient post-earthquake search and rescue operations.

Coastal landslides are also of major concern to India. India's 5700 km long coastline, especially the 2700km bordering Bay of Bengal is frequently being affected by storm surge induced landslides causing enormous land loss. Coastal stability of slopes has assumed a high importance also because of the threats posed by anthropogenic factors and tsunami.

High altitude problems of landslides affecting India chiefly relate to glaciers and snow avalanches. Bullet like fragments of shooting rocks, rapid motion snow avalanches and death trap of crevasses have humbled some of the ace mountaineers of the world. In the awake of climate change, study of glaciers and avalanches deserves much greater attention.

The Indian Ocean tsunami of December 2004 has renewed the interest of scientists in study of underwater landslides (submarine slumping) which may become instrumental in triggering tsunamis. There are no studies or scientific records of underwater landslides in Indian Ocean region and represents an important knowledge gap which is of concern to Sri Lanka and Maldives as well.

The Government of India decided to setup taskforces for Landslide Hazard Zonation Mapping with Geological Survey of India as the nodal agency. At the very same time the Department of Science and Technology was designated as the nodal agency for landslide research and the Ministry of Environment and Forest was named as the nodal agency for Landuse Zonation and Regulation. In pursuance of the Government order, the Department of Mines entrusted GSI with the responsibility to review the existing methodologies for landslide Hazard Mapping, prioritize the mapping work and recommend a plan for preparation of hazard maps. GSI has reportedly prepared LHZ maps on 1:50,000/25,000 scale covering about 45,000 km^2 area in the landslide prone hilly tracts of the country.

Department of Science and Technology of the Government of India, Central Road Research Institute in New Delhi, Central Building Research Institute in Roorkee, Border Roads Organization, Wadia Institute of Himalayan Geology, Dehradun, Defence Terrain Research Laboratory of the Ministry of Defence, Snow and Avalanche Study Establishment in Chandigarh, National Remote Sensing Agency, Centre for

Disaster Mitigation and Management, Vellore and Central Water Commission are some of the leading organizations working on diverse aspects of landslides.

National Disaster Management Authority (NDMA) of the Government of India, established in 2005 has taken a number of highly significant initiatives towards landslide risk reduction building on the strong foundation laid by the High Powered Committee, through its report submitted in October 2001. The first landmark initiative of NDMA was to publish National Guidelines on Management of Landslides and Snow Avalanches in June 2009 after deliberations spread over almost two years. The National Guidelines covers almost all components of the landslide management process, namely, landslide hazard, vulnerability and risk assessment; multi-hazard conceptualization, landslide remediation practice, research and development, monitoring and early warning, knowledge management, capacity building, training, public awareness and education, emergency preparedness and response, and techno-legal regime.

For speedy implementation of the Guidelines, Geological Survey of India in the Ministry of Mines has been designated as the nodal agency. Another landmark initiative is the proposal to establish Centre for Landslide Research, Studies and Management (CLRSM). It will be established by the Ministry of Mines as a premier Geohazard institute with state-of-the-art facilities. The commitment of the Government of India to effective landslide risk management is also reflected in its initiative by its Planning Commission to constitute a Working Group on Disaster Management for drafting of the XII Five Year Plan. It shows country's commitment to mainstream disaster risk reduction into the process of development planning at all levels for sustainable development, as stated in the Hyogo Framework for Action 2005-15.

National Institute of Disaster Management is, inter alia, mandated to carry out training programmes on diverse aspects of landslides including Comprehensive Landslide Management. It may not be out of place to mention that the concept of Landslide Disaster Knowledge Network originated in India in the early 2000 and this will now be a subset of SAARC Disaster Knowledge Network[8].

Maldives

The Republic of Maldives comprises 1192 small, low lying coral islands in the Indian Ocean. Of these, habitated islands number no more than a couple of hundred. The total area of Maldives is around 300 sq km.

Maldives is a nation of islands. This is especially worrisome in the wake of alarming predictions made by the International Panel on Climate Change. It was among the most severely affected countries when the Indian Ocean Tsunami struck on 26 December 2004. The weather in Maldives is dominated by two monsoon periods, namely, the south west monsoon from May to November and the less severe north-

8 R. K. Bhandari (2000): Disaster Knowledge Network. A Chapter contributed to the High Powered Committee on natural Disasters constituted by the Government of India.

east monsoon from January to March. The average annual rainfall reported on the basis of measurements made at three Meteorology Stations range between 1818mm and 2299mm[9].

The disaster risk scenario of Maldives has been described as moderate. It is regularly exposed to storms, cyclonic waves and heavy rains. The main threat it faces is from sea level change particularly because it stands barely 2m above the mean sea level.

Figure 6*: Tetrapod Technology is extensively in use in Maldives. The picture shows a Tetrapod on public dispjay at Male. (Courtesy: R. K. Bhandari)*

Figure 7*: Tetrapod Technology is extensively in use in Maldives. The picture shows a Tetrapod wall protecting a coastal slope. (Courtesy: R. K. Bhandari)*

Protection of slopes through tetra pod technology so commonly in use in Maldives is of considerable interest to many of the SAARC countries including Sri Lanka, Bangladesh and India, Figures 6 and 7.

The Disaster Risk Profile for Maldives, projected in November 2005, by a study conducted by RMSI at the instance of UNDP, Maldives, was the first major effort towards disaster risk reduction. Various ministries and departments of the Government of Maldives were associated with this study. The report, inter alia, identifies top 20 islands prone to earthquake hazard,top 20 islands subjected to water-storm risk, and top 20 islands exposed to tsunami risk[10].

Nepal

Nepal covers an area of about 147181 sq km and lies mostly in the central part of the Himalayas and measures 125km -250km north-south about 885km east west. Types of hazards facing Nepal have been discussed in several publications. [11]

Geologically, Nepal is located on the boundary between the Indian and the Tibetan plates. Physiographically, Nepal can be classified into three zones, namely, the mountainous region (height above

9 Report on Developing Risk Profile for Maldives, Volume 1, November 2005. Submitted by RMSI, India
10 RMSI-UNDP (2005): Developing a Disaster Risk Profile for Maldives. Volume 1.
11 K.P. Parajuli (2006) Management of Natural Disasters in the book on Natural Disasters in Developing Countries published by NAM S& T Centre, New Delhi.

3000m) covering 25.5 %, the middle hills between Mahabharata range and High Himalaya (height from 400m to 3000m) covering 60% and the Southern plains including Churia hill, Dun valleys and Terai (200m to 1000m high), covering the remaining 12.5%[12]. The remarkable physiographic contrast is obvious when once looks at the dramatic drop from the highest point at Mount Everest to the lowest point in the eastern Terai in just 200km.

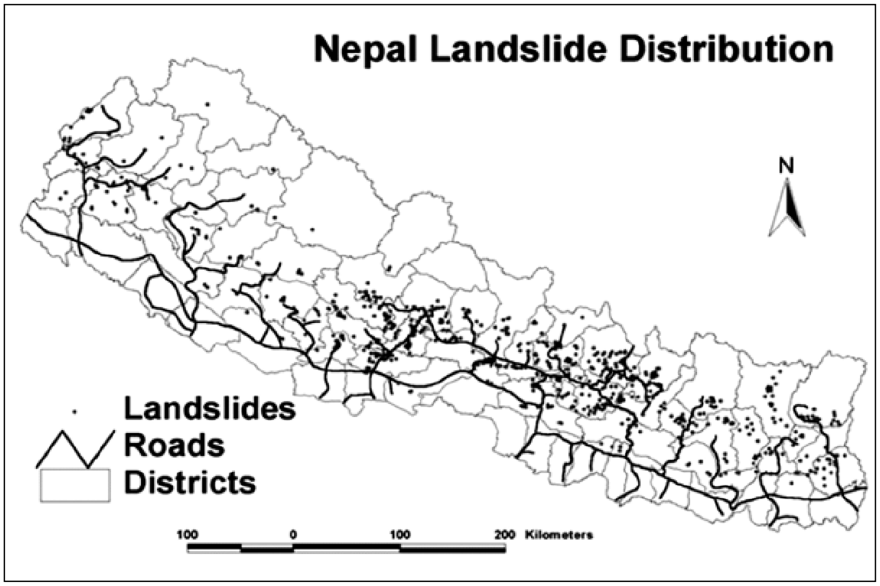

***Figure 8:** Landslide Distribution Map of Nepal (Source: Durham University)*

The vulnerability of Nepal to earthquakes, landslides, avalanches, glacial lake outburst floods and consequent debris flows is well known. Nepal is hugely vulnerable to landslides because of its steep mountainous terrain, high population density, over grazing of protective slope cover, deforestation, monsoonal climate and feverish pitch of urbanization. Eight of the world's ten highest peaks and nine of the 14 peaks exceeding 8000 m fall in Nepal. Imagine what could possible happen in terms of landsliding when climatic physiographic contrast, the climatic contrast and the human violence against our mountains co-exist. As to be expected, one can find landslides of every type and description. Landslide distribution Map of Nepal is shown in Figure 8.

Landslides have often halted development in Nepal. A huge landslide struck the reservoir area of Chisang Khola Hydro-electric unit in 1964. It blocked the Chisang River for 14 days, submerging the entire power house and inflicting huge damage. Landslides are known to disrupt road and communication networks, especially in the monsoon season. Tribhuvan Rajpath which connects the capital city Kathmandu with India carries numerous scars. Three of the major slides were reported are at Nagdhunga, before Tistung and after seven loops, and near Bagmara. All of these lie in fractured dolomite phyllite zone[13]. There are problems of landslides on Arniko Highway, Siddhartha Highway and Prithvi Highway[14] as well though the degree of severity varies. Noteworthy on the Arniko Highway is the landslide near Dolaghat where the road traverses through carbonaceous shale zone and shear zones. On

12 Regional Study on the Causes and Consequences of Natural Disasters and the Protection and Preservation of Environment. A publication of the SAARC Disaster Management Centre, New Delhi, pp 37 and 44.

13 Chandra K Sharma: Landslides and Slope Erosion in Nepal, published in 1976, pp 79.

14 Arniko Highway connects Kathmandu with Tibet/China. Prithvi Highway connects Pokhara with Kathmandu and Siddhartha Highway connects Pokhara with India.

Siddhartha Highway too numerous landslides are seen in the valley of Andhikhola. Here too carbonaceous shales are found. Muglingtar landslide is one of the major slides on the Prithvi Highway.

There are several examples of landslides destroying road infrastructure. The landslide of 10 September 1978 which struck at 12 noon destroyed a RCC bridge of East-West Highway even before it could be inaugurated. Landslide Hazard Management on Kodari Highway is shown in Figure 9. It carries inset of Jogimara landslide.

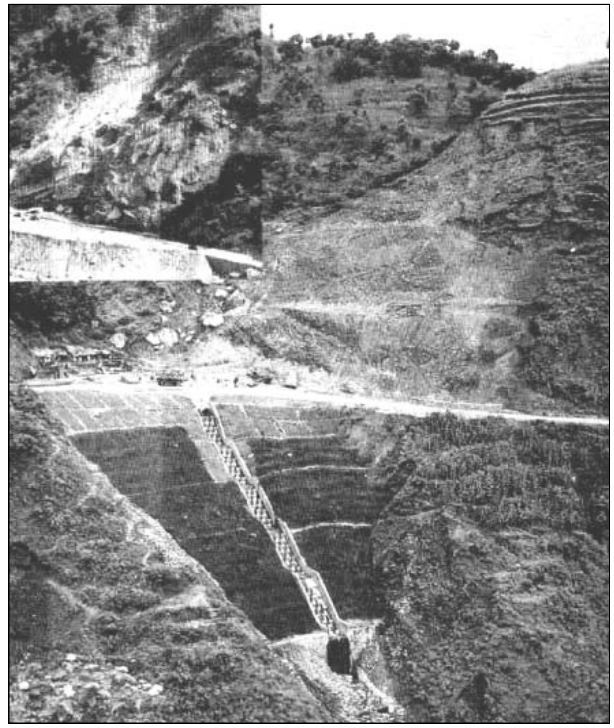

Figure 9: *Landslide Hazard Management on Kodari Highway in Nepal (Courtesy: B. N. Upreti and M. R. Dhital)*

Earthquake Induced Landslides triggered by Bihar Nepal earthquake of 1934 threw up great lessons for south Asia, some of which are still to be learned before the next earthquake strikes

Glacial erosion, avalanches and rockfalls are common especially in northern Nepal. Rock avalanches have played havoc with Ramche village in Trisuli valley of central Nepal, Taplejung in eastern Nepal and near Kaligad in far western Nepal

Nepal has witnessed numerous cases of landslides due to bursting of landslide dams. In 1978, following a cloud burst, a landslide blocked a river to create a landslide dam the breach of which released a massive flood wave wiping out Dauretole of Butwal causing enormous damage to life and property. Debris flows due to Glacial Lake Outbursts have also ravaged parts of Nepal several times. Five GLOF events occurred in Nepal between 1977 and 1998 as revealed by study of satellite imageries. Six GLOF events between 1935 and 1981, originating from Tibet, China were reported to have damaging effect inside the Koshi river basin in Nepal.

Landslides threaten cultural heritage as well. The famous Dakshinkali Temple located in the southern part of Kathmandu Valley is known to be threatened since the rains of 1975 when excessive slope subsidence was reported[15].

Pokhara valley, Sun Koshi catchment and upper Arun catchment receives 4 metre of annual rainfall on an average whereas like Dras in India, the trans-Himalayan areas of Jumla or Mustang get hardly 25 cm,

15 Chandra K Sharma: Landslide and slope erosion in Nepal, published in 1976, pp 79.

that is, sixteen fold less. Cloud bursts delivering 200-300 m just in a 24 hour period are generally associated with landsliding and flash flooding.

Nepal suffers from heavy landslides on the southern flank of the Himalayan range, especially in the middle and low Himalaya. A great majority of them occur during the late monsoon period when pore water pressure builds up in the slope mass. One of the databases report recorded deaths of 185 in 2001, 342 in 2002 and 244 in 2003. During the period 1970-2000, the fatalities due to landslides averaged at 65 per annum. Impact of landslides is clearly visible on Nepal's hill roads. Nepal's national network has reportedly increased from 3173 km in 1974 to 13709 km in 1998.

It is also the repository of some of the best examples in bursting of Glacial Lakes creating many Landslides. Nepal's Triangular High Altitude Observatory is also a great asset in real time monitoring of mountain systems.

Nepal pioneered the Landslide Hazard Mapping work which eventually influenced mapping in Sri Lanka. It was Wagner who started Landslide Inventory Mapping in Nepal in 1983. Keinholz and others thereafter developed much improved landslide Susceptibility Mapping Technique in 1984. In a paper published in 1985, Keinholz[16], perhaps for the first time, presented a methodology for assessment of slope stability in the Nepalese middle mountains for the densely populated hill areas. This work was continued by Zimmerman in 1986 and White in 1987. In later years application of GIS gave a big thrust to the mapping work as seen in the work of Thapa and Dhital in 2000. Nepal has the weight of history and experience to give thrust to SAARC Programme on Landslide Hazard Mapping. In a study funded by the UK Department of Internal Development, landslide hazard and risk mapping in Nepal, it was concluded that the mapping technique was well received both in Nepal and Bhutan. The authors summed up the study by saying that"we do not see the methodology presented here as the definitive technique for hazard and risk mapping in Nepal and Bhutan, but we do consider it to be an effective technique for at least gaining an impression of landslide susceptibility, hazard and risk in low cost road planning"[17] .

It has institutional mechanism which can substantially strengthen SAARC initiatives in Landslide Studies & Research. ICIMOD has developed a comprehensive training manual in six volumes for middle level professionals. Department of the Geology and Mines is the Government institution engaged in the study of landslides and mass wasting.

Nepal Army and Nepal Police have displayed considerable experience in dealing with rescue and relief operations. One of the recent examples is of rain-induced landslides at Baglung and Bajura which

16 Keinholz, H (1985): Assessment of Slope Stability in the Nepalese Middle Mountains. Proceedings of IV International Conference and Field Workshop on Landslide held in Tokyo, pp5-10

17 David N Petley, Gareth J Hearn and Andrew Hart (2005): Towards the Development of a Landslide Risk Assessment for Rural Roads in Nepal. In the book on Landslide Hazard and Risk, a John Wiley Publication pp597.

occurred on 12-13 July 2007. According to the Nepal Red Cross Society, 35 people were killed, 4286 families were hit, and a total of 24961 people were affected through out the country. Relief and Rescue operations were directed by Government of Nepal and supported by Nepal Red Cross Society.[18]

The challenges of landslide disaster management, rescue and relief become daunting when before the pain of one disaster is over the next one strikes. This is what happened in south-central part of Nepal during 19-21 July 1993, following unprecedented rain which breached all records when it measured 540mm in a single day. Closely on the heels of this occurred another spate of landslides and floods on 8-9 August 1993.The total effect of the two events was 1460 people dead or missing, 73606 families seriously affected, 39043houses destroyed, 367 km of roads damaged, 213 bridges destroyed, among other damages[19].

Commitment of the Government of Nepal to Disaster Risk Management has come a long way since the days of Natural Calamity (Relief) Act 2039 which was enacted in 1982. This Act, even at that time, recognized landslides among other disasters such as earthquake, fire, flood, drought, storm, famine and epidemics. Central Disaster Relief Committee established under the Act was responsible for disaster administration in Nepal. Since this Act addressed mainly the relief aspects of disaster management, it was amended in 1992 to stress on preparedness and mitigation aspects. Further stimulus to disaster risk management came with constitution of IDNDR National Committee under the Chairmanship of the Minister of Home Affairs. The National Action Plan for Disaster Reduction prepared by this committee was presented at the IDNDR mid-term review in Yokohama in 1995. The updated version of the Plan was accepted by the Government for Implementation during 1996-2000. To prevent water-induced disasters, the Government of Nepal also signed an agreement with the Government of Japan to establish Water Induced Disaster Prevention Technical Centre in Nepal. The other initiatives taken include setting up of a National Working Group to prepare a National Action Plan on Landslide Hazard Management and Control. This effort resulted in development of detailed Manuals for training on Integrated Landslide and Debris flow Management and Control[20].

The Tenth National Development Plan (2002-2007) of Government of Nepal, for the first time in its history, included two chapters on Natural Disaster Management. The Three-Year Interim Plan (2007-2010) also includes a separate chapter on Natural Disaster Management while stressing the DRR concerns in other development sectors.

The Government of Nepal solicited UN support in launching a project during 1989-1992 aiming at preparation of a comprehensive Disaster Management Plan and establishing institutional mechanisms for its implementation.

18 South Asian Disaster Report 2007, pp 109.
19 Amod Dixit (1996): Disaster Management in Nepal- A Country Report prepared for UNCHS (Habitat) and UNDP.
20 ICIMOD Publication: Partnership in Sustainable Mountain Development (1995-1998), pp16.

Pakistan

Pakistan covers a total area of 79609 sq km and ranks very high in population density. It extends from over 1000km from north to south and about 885 km from east to west.

Pakistan is a land of contrasting relief. A series of High Mountain ranges lie in the north from east to west .These mountain ranges include Himalayas, Karakoram and Hindu Kush. The Himalayas in the eorth east climax in some of the highest peaks yielding average elevation of as high as 6100m. On the north west of Himalayas lies the Karakorum range which extends all the way upto Gilgit. K2 the second highest peak falls in this range rising to 8611m. The Hindu Kush Mountains extend eastward into Afghanistan with its highest peak Tirich Mir at 7736m.

Physiologically speaking, Pakistan has two distinct provinces, namely, the Western Highlands and the Indus plains. The western highlands can be further classified into five divisions; (1) Mountainous North (2) Safe Koh and Waziristan Hills, (3) Sulaiman and Kirthar Mountains (4) Balochistan Plateau, and (5) Potwar Plateau and the Salt Ranges.

The Mountainous North includes Himalayas, Karakoram and Hindu Kush. The higher peaks are known to remain snow bound most of the time. Some of the major glaciers are Siachin, Hispar, Biafo, Batura and Baltoro.

Climatologically speaking, Pakistan is blessed with a great variety of climatic diversity ranging from the hottest Jacobabad and Sibi districts to snowy cold of Balochistan. Pakistan is on the margins of the monsoonal climate which is why the rainfall is insufficient. The mean annual rainfall in the mountain region is about 1020mm or more. Murree receives annual rainfall of about 1640mm Sindh and Balochistan receives scantly rainfall. The western depressions originating from the Mediterranean region bring rainfall in winter [21].

North West Frontier Province, Pakistan administered Kashmir, Punjab and Balochistan are among the worst landslide hit areas.

Most spectacular recent experience has been with devastating earthquake-induced landslides on the steep mountains of northern Pakistan following the massive Muzaffarabad earthquake of 8 October 2005 measuring 7.6 on the Richter scale. During this earthquake Neelum valley witnessed numerous landslides. The area has such a high affinity for landsliding that on 21 March 2007, a spate of landslides occurred at Doba Syedan village, triggered by near continuous torrential rainfall. In another event on the 25 March, a landslide in the Neelum valley killed 7 people, injured 4 and destroyed 3 houses. Murree is yet another area in northern Pakistan highly prone to landsliding.The town of Murree is about

21 Pakistan Country Report (Working Draft) for the consultative meeting for exchange of national experience on disaster management submitted to UNCHS (Habitat) for meeting in Colombo during 9-14 December 1996.

50km to the northeast of Islamabad at an elevation of 2200m. Two of the major landslides are Chitta Mor and Kashmiri Bazar Landslides.

Karakoram Highway between Gilgit and Rawalpindi provide numerous landslide locations such as Pattan, Tatapani, Bisham and Thakut. On 4 January 2010, devastating landslides in Atta Abad and Sarat villages in the Hunza Nagar district in the northern region of Gilgit killed more than 10 people. The predominant class of landslides on Karakoram highway is debris flows that move down the steeply dipping foliation planes.

Some of the more recent notable landslides include those in 2008 which killed 24 people in Swat, Gilgit, Rawalpindi, Quetta and Muzaffarabad areas. On 18 January 2008, two persons were killed and four injured near Simani on the Neelum Valley road. In another incident on the night of 3 February 2008, six children were killed and three others injured in the Bibi Nari area of the Bolan district. Again six persons were killed by a rain-induced landslide in Maiden, Upper Swat Valley on 25 May 2008. Similar incidence occurred on 6 August 2008 in Gilgit killing 7 people at Hilabad village.

In the Valley of Jehlum River near Pir Panjal Range of eastern Pakistan, the red shales of the Murree formation are highly problematic from landslide point of view. Toe erosion of thick sediment cover in the valley has been responsible for many major debris flows.

Problems of slope instability in Pakistan faced at the Mangla dam site were responsible to have lifted the Geotechnique of slope engineering several notches higher. Our concept of residual strength in slope instability would have not advanced so fast but for the study of shear zones at Mangla dam carried out under the direction of legendary Professor A. W. Skempton.

There is an interesting case of early warning reported signaling a rockslide on the right abutment hill of the Tarbela dam site at about 0530 hrs on the 27 January 1982[22]. Sirens were activated a couple of minutes before the slide and were helpful in giving time to clear the area. Pakistan also has considerable experience in responding to landslide disasters. When the toll due to landslide rose to 46 on 22 March 2007, prompt relief was possible thanks to the effort of Pakistan army, the International Agha Khan Network Charity and United States Agency for International Development.

The disaster management in Pakistan, as in the case of countries like India, Nepal and Sri Lanka followed relief-centric approach. The role of federal Government, according to one Pakistan Country Report, has been one of coordination of relief distribution, international resource mobilization, attending to post disaster surveys and enquiries, etc. Much of what happened was guided by West Pakistan National Calamities Act of 1958. But things have perceptibly changed, especially since the passing of National Disaster Management Ordinance in 2006. The implementation of the ordinance will be ensured

22 Abdul Khaliq and Izharul Haq (1984): Rockslide Right Abutment Hill-Tarbela. Proceedings of the IV International Symposium on Landslides held in Toronto, Canada. Volume 1, pp529.

by the National Disaster Management Commission headed by the Prime Minister. The National Disaster Management Authority is the focal agency in Pakistan for coordinating and facilitating implementation of strategies and programmes on disaster risk reduction, response and recovery. Of the many programmes initiated to facilitate the integration of disaster risk reduction into development planning, the one called National Capacity Building for Disaster Risk Reduction (NCBDRM) covers the whole country and will be spread over a five year time frame. NDMA has also given impetus to comprehensive risk analysis and hazard mapping of Pakistan. The digitized hazard maps are proposed to be integrated into the GIS system for reliable and timely decision-making.

Government of Pakistan's strong commitment to the cause of disaster management is also reflected in its initiative to establish the National Institute of Disaster Management and integrate disaster risk reduction education in the school, college and university curricula. Surely enhanced capacity in landslide management will flow out of these, and numerous other programmes perceived by the NDMA. Development of National Hazard Atlas of Pakistan, National Response Plan and establishment of National emergency Operation Centre are already on the agenda[23].

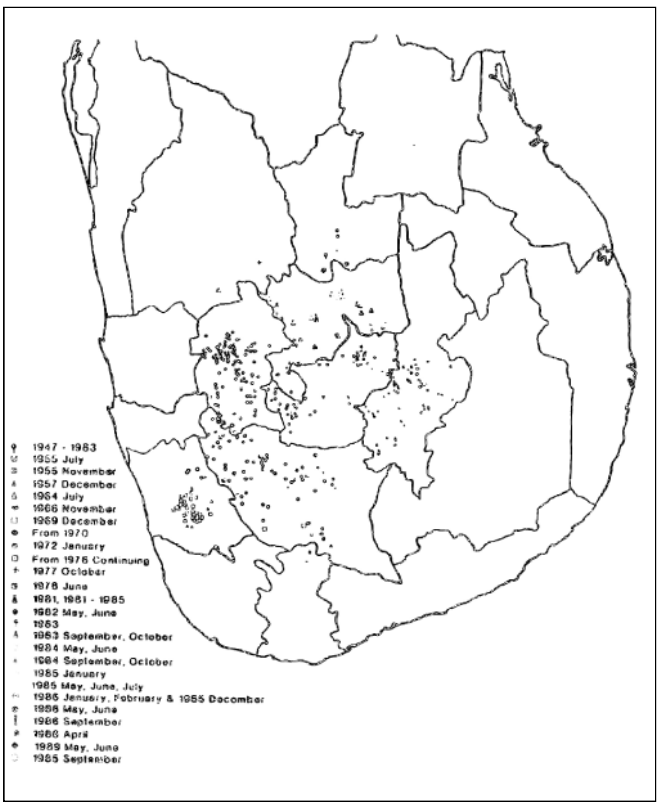

Figure 10: *A map of landslide distribution in Sri Lanka (Source: National Building Research Organization, Colombo, Sri Lanka.*

Sri Lanka

Major threats of natural disasters in Sri Lanka come from landslides. Landslides literally dot over 10 000 sq km of Sri Lanka's ten districts Nuwara Eliya, Badulla, Kegalle, Ratnapura, Kandy, Kalutara, Galle, Matara, Hambantota & Matale, Figure 10.

Recall the major devastating events of 6-10 January 1986 which killed people in Mandaranuwara, damaged houses, paddy fields, roads and a bridge at Madulla, and a hospital in Mulhalkele. Three years later, on 3 June 1989, landslides killed 14 persons in Mamaduwa, 24 persons in Neluwattukanda of the Kegalle District and 8 persons at Paraiyagala in the Nuwara Eliya District. Four years there after, on 8 October 1993, an earth flow at Helauda on the Ratnapura-Wewelwatta road killed 31 people at the foot of a slope, Figure 11. In the year 2003, another 8 landslides occurred, killing 114 people.

23 NDMA Pakistan (2009): Progress achieved in the Field of Disaster Management in Pakistan. A paper published in the SAARC Workshop on Earthquake Risk Management in South Asia, Islamabad, Pakistan, 8-9 October 2009.

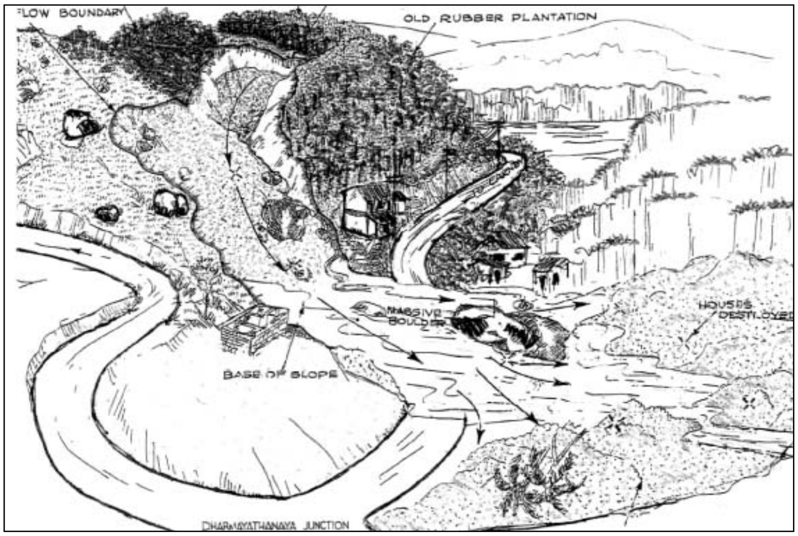

***Figure 11**: An artist's impression of the Helauda Earthslide in the Ratnapura district of Sri Lanka (Artist: Sunil Fernando under guidance of R. K. Bhandari).*

The floods and landslides of 1989 which affected districts of Colombo, Galle, Gampaha, Kalutara, Kegalle, Matara and N'Elia were estimated to cost Rupees 1420 million in 1989[24] . Those due to floods and landslides in May 2003 were about Rupees 6593 million[25]. During the periods 1981-91 and 1993-2001, drought relief cost about Rupees 1901 million.

Commitment of the Sri Lankan Government to landslide risk reduction is absolute. As far back as 15 December 1989, the Government of Sri Lanka launched a full scale Landslide Hazard mapping Project (with assistance from UNDP and UNCHS) which came to fruition with the delivery of state-of-the-art landslide hazard maps by July 1995. This project climaxed into establishment of a full fledged Landslide Studies and Services Division at the National Building Research Organization (NBRO), which was designated as the nodal agency for landslide management in the country. NBRO has in place a well established and highly acclaimed programme of completing the Landslide Hazard Mapping of the entire country at a scale of 1:10 000.

Thanks to the UN supported project that Sri Lanka became the first country in the world to successfully deploy the most modern subsurface drainage technology using directional drilling to control a 100 year old and nearly intractable Watawala Landslide. This Sri Lankan experience is an invaluable message and learning experience for other countries of the SAARC region.

Recognizing the holistic nature of national initiative on disaster management, the then Ministry of Policy Planning and Implementation, and the Ministry of Rehabilitation, Reconstruction and Social Welfare Ministry of the Government of Sri Lanka jointly drafted a National Disaster Preparedness and Mitigation Plan in January 1992. A committee of Officials appointed by the Cabinet Sub-Committee on Natural Disasters submitted its report in February 1993. This got further stimulus with the two workshops conducted in July and December 1994 to mark the International Decade for Natural Disaster Reduction. In July 1996, the Government of Sri Lanka established the National Disaster Management

24 UNDP Report (SRL/89/016): Johan. P.Buwalda and Tom M. Wolters on Floods and Landslides 1989, Sri Lanka

25 National Disaster Management Plan, Fourth Draft, October 2007. Page 23.

Centre (NDMC) under the Ministry of Social Services. NDMC became instrumental in building on the past effort to drafting Sri Lanka Disaster Management Plan 2008-2012.

The Disaster Management Act No13 was enacted in May 2005 providing a strong legislative and institutional framework for Disaster Risk Management. The Act established National Council for Disaster Management under the Chairmanship of the President. In November 2005, the Ministry of Disaster management was established which is currently under the charge of Minister of Disaster Management and Human Rights.

Commitment of the Government of Sri Lanka to Landslide Risk Reduction was underscored once again by the Minister on 12 November 2009 while inaugurating a National Symposium on Creating Disaster Free Safer Environment at the Silver Jubilee function of NBRO, the lead agency in Sri Lanka for landslide management.

The strategy proposed in the Road Map for Disaster Risk Management has seven thematic components, namely, Policy, Institutional mandates and Institutional Development; Hazard Vulnerability and Risk Assessment; Multi-hazard Early Warning systems; Preparedness and Response Plan; Mitigation and Integration of Disaster Risk Reduction into the Development Process; Community Based Disaster Risk Management and Public Awareness, Education and Training.

Some Major Areas of Shared Interests

SAARC countries do not have to build their capacities to manage landslide risks from the scratch. For decades, SAARC countries have lived through and experienced landslide disasters. They have learned from landslides and have managed them with increasing degree of maturity and preparedness. They have also, knowingly or unknowingly, inspired, influenced and helped one another in the pursuit of landslide risk management. The paper proposes to flag some major areas of common interest in order to serve as a framework for discussion.

While the types of landslide problems of current concern are to be addressed, It will be also essential to add emphasis to the rapidly emerging new set of problems due to climate change, environmental degradation, enhanced vulnerability to Glacial Lake Outburst Floods (GLOF) and earthquake induced landslides. All these topics are of shared concern with expanding body of knowledge base. For example, the threat from GLOF is faced by several of the SAARC countries because of about 15000 glaciers and 9000 glacial lakes in Bhutan, Nepal, India, Pakistan (and China). This was reported in a baseline study conducted by the International Centre for Integrated Mountain Development of Nepal, United Nations Environment Programme and Asia Pacific Network for Global Change Research. Of the 2315 glacial lakes, 26 potentially dangerous glacial lakes are in Nepal. The bursting of Glacial Lakes in the mountains of Nepal carries the potential of ravaging parts of India down stream. It is to be noted that the National Action Plan for Adaptation (NAPA) to Climate Change prepared by Bhutan and National Communication on Climate Change Mitigation and Adaptation brought out by the Government of India have also placed considerable focus on GLOF vulnerability *reduction factors*[26] . In May-June 2008, Glacial Lake Outburst Floods hit three villages Passu, Ghulkin and Hussain in Gojal Tehsil of Pakistan disrupting trade and traffic on the Karakoram Highway[27].

Landslide Hazard Mapping, Vulnerability and Risk analyses is another area which can be placed on a SAARC launching pad with a modicum of effort. In 1980, when India hosted the third International Symposium on Landslides, the Landslide Hazard Mapping got highlighted as the first paper of that symposium. Closely on the heels of this, Nepal came out with a set of landslide hazards maps at a scale of 1:10 000 published in 1980's. The Nepalese work gave impetus to the Sri Lakan landslide hazard mapping programme (1990-1995). And, Sri Lanka came out with a set of 30 Landslide Hazard Maps covering about 7500 sq km of its Central Highlands at a scale of 1:10 000. These were the first set of ground validated landslide hazard maps in south Asia. The mapping methodology developed for Sri Lanka came as a trigger for India and led to production of the first small scale landslide hazard map of India in 2001. Since then, many institutions in the SAARC region are doing the landslide hazard mapping work but without learning from one another or without even making an attempt to agree on to the basic terminology and classification of landslides and mapping scale, not to speak of broad agreement on mapping methodology and approach to Vulnerability and Risk Assessment. The early signals from the IAEG Working Party on Landslide Inventory were picked by Sri Lanka as far back as March 1994, but this effort attenuated without stimulating action in the other SAARC countries. The quality of scientific documentation and of the benefits of investments made by the various national Governments will be much higher, if the consultations between member States could lead to general consensus on the whole range of fundamental issues such as standardization of definitions and terminology, adoption of the most appropriate landslide classification system, and broad agreement on the approach to landslide hazard mapping and vulnerability and risk analysis.

The snapshot of landslides in the SAARC countries discussed in this paper should leave one in no doubt that combined value of the experiences gained by individual member States could be of path breaking value in landslide risk management. Take for example the experience of dealing with earthquake induced landslides which invariably block post earthquake relief and rescue operations. India and Pakistan together faced the havoc of earthquake-induced landslide after the Muzaffarabad earthquake of 2005. These landslides blocked the roads disrupting the entire communication system at the time it was needed the most. Afghanistan, Nepal and Bhutan have also gone through similar experiences. We need to ensure that, earthquake and landslide hazard assessment approach, which currently do not take into account earthquake-induced landslide, is critically reviewed and improved .

When the landslide disasters cut across national boundaries, there is no way other than to study the landslides through a joint initiative. When the Great Malpa Tragedy struck the Indian state of Uttarakhand, obliterating the entire village of Malpa for ever, only the Kali Nadi stood between India and Ne-

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pal and there were spate of landslides on both sides of the territorial divide suggesting that a joint initiative would be the best way of managing such landslide risks in future. Then other countries of the region can also add value to such studies by bringing in their own pool of experience. For instance, Sri Lanka had gone through a similar experience that India had at Malpa. More than 200 pilgrims got buried under the Malpa rock avalanche at the foot of the slope, Figure 12. In Sri Lanka, when the Helauda Earthslide struck, 31 people got buried alive at the foot of a slope, Figure 13.

Figure 12: *The Rock Avalanche which killed about 220 people in the State of Uttarakhand in India buried the village of Malpa under heaps of debris at the foot of the slope. High vulnerability of human settlements at the foot of a problematic slope represents a typical situation that call for pro-active mitigation measures.(Courtesy : Kishor Kumar)*

Figure 13: *A landslide catastrophe similar to the Malpa Rock Avalanche tragedy in India (Figure 19 above) occurred at Helauda in the Ratnapura district of Sri Lanka. (Courtesy: R. K. Bhandari)*

There are also invaluable experiences gathered by the SAARC countries with management of landslide disasters on roads and railway lines over decades. Many of the landslide problems are active for decades and piece-meal efforts to control them have been in vain. There are, however, some outstanding examples in some countries others can benefit from. Take for instance; the formidable Watawala Earthslide which disrupted a stretch of the railway line from Colombo to Badulla for more than 100 years, Figure 14. The problem became intractable in 1992. Sri Lanka made a history of sorts when this landslide was completely controlled through first time use of directional drilling of mountain slopes for subsurface drainage. India

Figure 14: *The more than 100 year old Watawala Earthslide in Sri Lanka was completely controlled through use of innovative subsurface drainage technology. Despite this, no other SAARC country has used this technology to control similar landslides. (Courtesy: R. K. Bhandari)*

has several similar landslide spots and one such is shown in Figure 15.

Bangladesh, India and Pakistan will similarly have a lot to learn from one another in the area of design and protection of flood embankments.

***Figure 15**: A landslide that destroyed a railway line in India. (Source: GSI Report)*

Some thoughts for Regional Cooperation

The following areas of concern seem to emerge as front runners in the race for prioritization and should serve as the framework for discussion, *mutatis mutandis*:

Exchange of experience warrants a common scientific language for scientific parlance, exchange of experience, regional and international communication and effective utilization of the fruits of research. Any effort to generate joint projects and programmes without uniformly understood landslide terminology, classification, mapping scales etc will mean building without a foundation. As of today, not to speak of a unified terminology and landslide classification system in south Asia, are marked variations seen even within the same country. This high yield –low investment action point is worthy of discussion.

Many SAARC countries are actively involved in landslide hazard mapping towards reliable landslide risk assessment. The methodology and infact the whole approach to landslide hazard mapping varies widely even within a country. What is most disturbing about some of the various ongoing mapping programmes is that landslide hazard maps often come to circulation even without their field validation and reliability certification. What every SAARC country requires is a set of user friendly large scale landslide hazard maps which are ground validated and certified for their reliability. The landslide hazard maps at appropriate scales are required as much for the advancement of our knowledge base as for planning, design and construction purposes. An agreed approach and methodology of landslide hazard mapping and risk assessment will give a big impulse to hazard mapping programmes, create base for scientific exchange of information between the SAARC countries and place the landslide risk management national initiatives in a much higher orbit. Do all the SAARC countries think that way, and if so, what could be done to achieve a common approach or a broad consensus on landslide hazard mapping approach and methodology?

Some of the worst landslide disasters have occurred in the South Asia and every country has gone through the trauma of the disastrous events and the experience of investigating, documenting and managing landslides. Even then, so far, there have been no significant attempts to co-relate the experiences of different countries in investigating and managing similar problems with better imagination, and create more effective documentation through writing of monographs, case histories manuals and guidelines. Such documentation will help boost the quality of landslide education and training at all levels. History is witness that well researched monographs on major disasters not only expand our body of knowledge but their influence travel through generations. The workshop will provide an excellent platform to discuss the whole idea of documentation of major disasters as the obligation of this generation to posterity. Whereas every country can document their respective major landslides, a monograph on major landslides of South Asia can come only through a joint initiative.

It is now well established that unlike earthquakes, most landslides could be predicted through a systematic programme of geotechnical investigation, instrumentation, and real time monitoring. Re-activation of most pre-existing as well as seasonal landslides falls in a well known class of problems amenable to reliable early warning. Case records of successful early warning against rock-falls are also not wanting. It may be a good question to ask in the workshop -why then the entire SAARC region does not have even a single inspiring example of early warning against landslides? What could be done to give impetus to landslide prediction and early warning and what ought to be the scope and thrust of a SAARC programme on landslide prediction and early warning?

Landslides hit harder when prompted by earthquakes. Earthquake triggered landslides constitute a major component to hazard due to earthquakes, and are known to badly hamper earthquake relief and rescue operations. The current practice of ignoring potential earthquake induced landslides in earthquake risk assessment is grossly unsafe and needs urgent review of current practices for future direction. It is important to answer (a) how reliable are earthquake and landslide risk assessment methods extant (b) how serious are the implications of such a neglect and (c) what needs to be done to introduce landslide concerns in earthquake risk assessment and seismic retrofitting programmes?

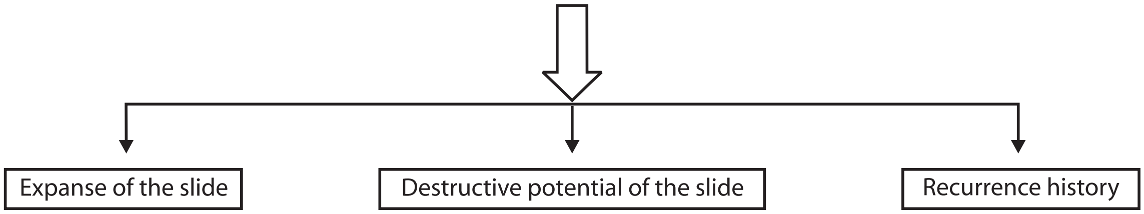
How do we proceed to establish a Landslide Disaster Knowledge Network as a vibrant component of SAARC Disaster Knowledge Network? How do we ensure sustenance of such an initiative? SAARC Disaster Management Centre has already come out with a publication on Indigenous Knowledge for Disaster Risk Reduction in South Asia, and the present workshop can add a new dimension to this SAARC initiative.

Baseline Information

Landslide Hazard Mapping, Vulnerability and Risk Assessment

A unified system of Landslide terminology and classification, established through a consultative mechanism is being generally favoured as a small but critical step towards landslide hazard mapping. Like other countries SAARC member states can also take advantage of the recommendations of the Working Party on World Landslide Inventory, the International Association of Engineering Geology Commission on Landslides, of the Technical Committee of the International Society of Soil Mechanics and Foundation Engineering and the pioneering works of J.N. Hutchinson that provide definitions of terminology connected with (1) Landslide Features (2) Landslide Dimensions (3) States of Activity (4) Distribution of Activity (5) Style of Landslide Activity and, (6) types of Landslides, based on collective wisdom, IAEG(1990); WP/WU(1990); WP/WU(1993); WP/WU(1994).

Landslide Hazard Asessment



Some vital Questions

Where will be landslide occur?
Reactivation of old landslides and seasonal rain-induced landslides are easy to demarcate. First time slides such as those generated by slope degradation processes or triggered by earthquakes or urbanization are not easy to locate.

When will the landslide occur?
Well monitored progressive landslides are usually not difficult to predict. Similarly, slides with known history of repetitive occurrences can be reasonably associated with rainfall or earthquake trigger. Once again first time slides defy reliable prediction.

What will be landslide type?
Geo-morphological mapping gives very clear indication of translation of translational slides such as slab slides. Mapping of rock joints provide clues to the form a landslide may assume. Simple slopes of near homogeneous materials may lead to rotational slides. Slope covered with colluvium or hill wash are likely to trigger debris flows or earth flows especially when provoked by rain.

How fast the landslide will travel?
Landslides occurring on well formed shear zones or discrete and softened slide boundaries may swiftly respond to sudden buildup of destabilizing forces and move very fast because of low sliding friction. Debris flows and similar other mass movements in their wetter manifestations could generate high speed over long distances. On the other hand, slope failures in cuttings and embankments move fast only briefly and come to rest soon after their occurrences

How far the landslide will move?
The distance traveled by a landslide will usually depend on mobility of the slide mass and characteristics of the slide boundaries.

How deep is the landslide and what order of volume involved?
Depth to length ratios of many types of slide seem to lie in indentifiable range.

What would be the nature and magnitude of damage?
It will depend on all the above factors.

***Figure 16** : The questions to be asked for landslide hazard assessment*

Definitions of the terms Landslide Hazard, Vulnerability and Risk already stand standardized the world over and may be adopted after due deliberation (Glossary of Terms). Vulnerability (V) to landslides can be evaluated only if we know the exposure, and our degree of preparedness to face that hazard. Threats of landslides to elements at risk such as housing and infrastructure, farms and fields, vast stretches of roads and railway lines, hydro electric, water supply, and transmission line projects, aerial ropeways, open cast mines, tunnels, heritage buildings and monasteries, pilgrim routes and tourist spots need to be considered. Route to landslide hazard recommended for assessment is given in Figure 16. Vulnerability is to be taken close to zero in the case of the well managed and protected slopes. It will be 100% for the unprepared population living on slopes with proven history of landslides.

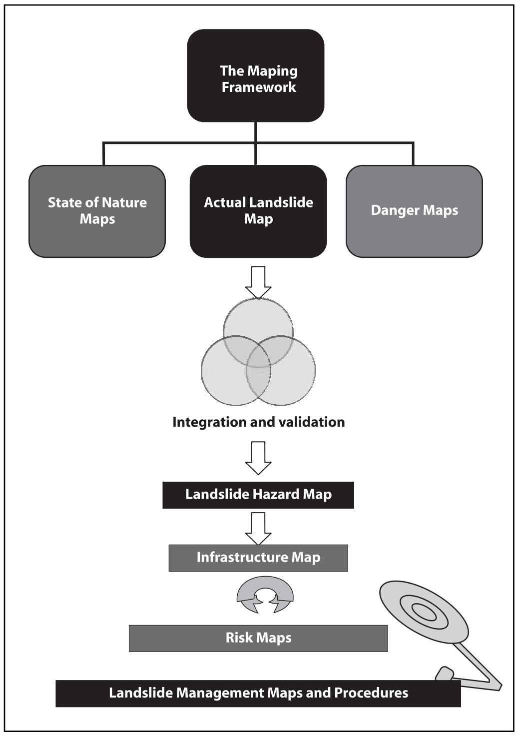


Figure 17: *Landslide Management Procedure.*

Once we know landslide hazard and vulnerability, specific risk, can be found as the product of Hazard (H) and Vulnerability (V). The total risk is then the multiplier of the specific risk (as calculated above) and the elements like population, property, infrastructure, and development activities exposed to landslide hazard. Risk maps are an asset to effective landslide management, Figure 17.

The main purpose of this exercise is to be able to visualize relationship between landslide hazard, risk and impact of a landslide, possibly in terms of quantified loss, for safer construction, Figure 18.

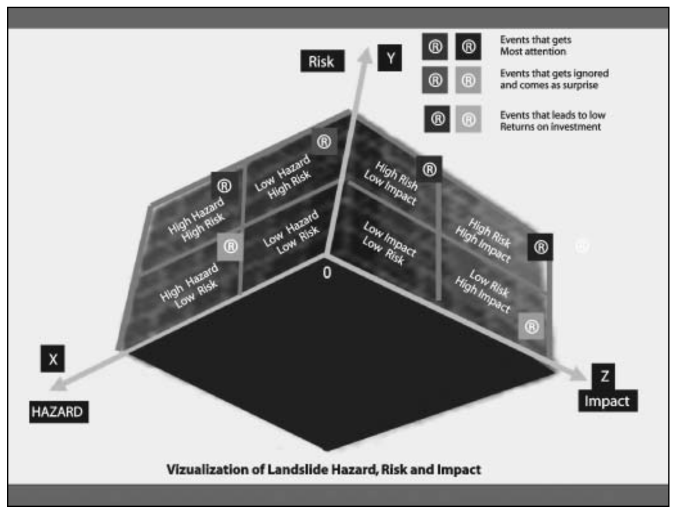


Figure 18: *Relationship between Hazard, Risk and the Impact of Risk . (Courtesy: R. K. Bhandari)*

Besides above, there is also the need to agree to common mapping scales. Recommendations for landslide hazard mapping at large, medium and small scale have been made by several international organizations and experts. Several agencies in South Asia have been pursuing landslide hazard mapping at scales either convenient to them or chosen for a specific purpose. We need to evolve a unified approach on this yet another vital matter.

Landslide Hazard Mapping in South Asia has so far been a sporadic activity based on some ad-hoc procedures adopted to suit a particular line of thinking or purpose. It will raise the value of these mapping programmes several notches higher if agreement between the SAARC countries could be reached on approach to landslide hazard mapping and on utilization of maps so produced for systematic landslide hazard assessment and risk evaluation.

Landslide hazard maps are obtained by integration of several factor maps such as topography, geology and gemorphology, land use and land management etc. It is therefore essential that the approach evolved by the SAARC countries for producing large scale landslide hazard maps not only reflect on approach to integration of factor maps but lay equal emphasis on making the maps user friendly, especially to architects, engineers, planners, builders etc. Needless to say those maps produced without ground validation and certification of reliability can at best be considered as work-in-progress. It is also useful to generate Digital Elevation Maps (DEM) of high resolution (1/2m interval along vertical) for the purpose of 3D terrain modeling.

Production of the various maps at large scale and their objective interpretations are beyond the capacity of any single agency. Multi agency projects with proven multi disciplinary expertise should, therefore, be encouraged, with an appropriate coordination mechanism.

Recognition of the Anthropogenic Factor in landslide studies and management

6.2.1 Let us ask the question- why the populated mountain ranges are invariably dotted with landslides in the first place? Conventional stale answer blames immature geology, steep slopes, meandering rivers, cloudbursts, flash floods, earthquake tremors etc., for this. This answer is far from true in most cases because these factors have co-existed with the slope for centuries. If at all, the time dependant changes in these factors have been, at best, marginal, spanning over generations. The real cause of slope instability and landsliding has been human intervention in terms of unplanned and non-engineered construction and development.

Vast mountainous areas have been robbed of the protective vegetal cover to less than 30 per cent as against twice as much considered desirable. With the exploding population pressure, more and more of human settlements, roads, dams, tunnels, water reservoirs, towers and other public utilities come up to respond to the felt needs. The network of roads in the Himalayan region today may run into thousands of kilometers. A number of dams have been built in the Himalaya despite fragile mountain ecology. A number of tunnels. Microwave, TV, transmission line and other towers are also dotting the hilly areas. Quarrying and mining operations have accelerated the process of slope degradation.

Climate Change and Landslide Hazard Mitigation

Whereas the whole range of issues connected with climate change including policies and Operational strategies are beyond the scope of this paper, unfolding consequences of climate change, insofar as mitigation of landslide hazards are concerned, deserve urgent attention. Rich global experience, especially on understanding and managing uncertain weather patterns and landsliding, glacial lake outbursts, landslide dam bursts and such other hazards, should help speedup our SAARC programmes to effectively deal with added uncertainties due to climate change. We need no more proof that our already "fragile" mountain systems, where most of the landslides occur, are being exposed to increasing risks due to climate change. In the coming decades, the negative impact of climate change will be exacerbated if the mounting human-induced pressures and mindless urbanization do not get checked.

Earthquake-Induced Landslides

A clear distinction is increasingly being made between the earthquake-triggered and earthquake induced landslides. Earthquake events are usually known to serve as a trigger for pre existing but dormant landslides to create what may be called earthquake-triggered landslides. Strong tremors, however, hold the potential to induce new slides especially by rupture along unfavorable discontinuities and shear zones. Such slides are designated as earthquake-induced landslides. It should also be recognized that the commonest classes of the best-understood problems are flow slides due to liquefaction. The other possibilities are (a) reactivation of old, dormant or previously inactive landslides (b) acceleration of known landslides (c) triggering of rock falls (d) development of fresh, first time landslides, and (e) on-set of slumping and braking up of the ground. The understanding of the whole process presupposes understanding of (a) topographic and hydrological controls, (b) geological and geotechnical controls (c) seismological controls and (d) anthropogenic controls.

Ground surface acceleration alone is a poor measure of the effect of shaking on slope stability, intensity even more so. The indicators such as ground velocity, experiences on past earthquake events, and duration of shaking are considered to be better indicators of landslide susceptibility under seismic conditions. Critical acceleration of a slope is also an important factor in deciding seismic safety of a slope. The factor of safety during an earthquake may drop below one (limit equilibrium state) for a short duration of time, but the effect of failure on the slope may perhaps be negligible, and needs to be determined.

The observation that catastrophic landslide events are a post-seismic phenomena rather than a co-seismic happening is still an unsettled issue which needs investigating. While the earthquake provides the trigger, the development of a landslide is seldom sudden, and is usually after the earthquake and its aftershocks.

Safety of Housing and Human settlements

The planning and design of human settlements in landslide prone areas is a task usually left to town planners, architects and engineers. Simple geological considerations are increasingly being appreciated in siting of human settlements. Architects are generally aware of the special consideration that goes into the design of human settlements on the hills vis-à-vis those on the plains. They, however, need to be educated on the special consideration that goes into the design of human settlements on the hills vis-a-vis those on the planes. They, also, need to be educated on the importance and highly specialized nature of landslide investigation, mapping and analyses which impact both on safety and economy.

Human settlements must be viewed not only from the perspective of their landslide vulnerability, but also from the perspective of the hazards that they create or exacerbate. There is a need to look closely at human settlements, especially those being built on problematic slopes by private builders and developers. If they were to be allowed to continue to build new settlements without recourse to proper slope investigation and timely protective action, (ignoring well known professional practices), landslide risk management will become even more difficult and expensive.

Site selection for housing, human settlements and other infrastructure in hilly areas must be done by a highly competent multi- disciplinary team of experts aiming to preserve the texture of the place, and its cultural fabric, maintaining balance between natural and anthropogenic factors. We need guidelines to remove conflict points between the growing developmental compulsions of sluggish economies in our hilly areas and the applicable techno financial and techno legal regimes. A casual approach to site selection and planning must be discouraged to facilitate well informed decision making based on systematically conducted investigations.

Growing density of population fuelled by increasing tourism has generated additional pressure of human settlements on already fragile slopes. Techno legal regime should be tightened to regulate new constructions strictly in accordance with the approved development plans.

The numerous human settlements are frequently seen on the valley floors, particularly alongside rivers and close to their tributaries, as also around lakes and water bodies. Many of these locations are highly prone and vulnerable to multiple hazards such as landslides, earthquakes, floods and cloudbursts.

Indiscriminate quarrying and mining operations for construction materials have also become a cause of serious concern on hills and will be strictly regulated.

Safety of Heritage and Lifeline Structures

Safety of many of our heritage buildings as well as lifeline structures stands visibly threatened by landslides and other types of disasters. In many cases the slopes supporting them are neglected. In some other cases only piecemeal effort is being made. For all important heritage buildings, systematic investigations should be carried out and remedial action taken by appropriate authorities to restore stability and conserve our heritage. Naturally this is an area of common concern to the SAARC countries.

Strengthening of Buildings on problematic slopes

One of the major concerns of disaster managers lies in avoidable deaths due to collapse of buildings- be that due to landslides, earthquakes or cyclones. Most SAARC countries deal with a huge existing housing stock of questionable safety and every year that housing stock grows resulting in a curious mix of engineered and non-engineered construction, and that too, on our already overstressed slopes. We also have a growing stock of formal and informal housing, multi-storied buildings and other structures such as heritage buildings, bridges, flyovers, and other infrastructure vulnerable to landslides.

Past experiences have taught us that non-engineered buildings may collapse due to a very large number of causative factors acting individually or in league with one another. Building super-structure may fail because of inadequacy of design, lack of ductility in structural members and connections, absence of shear walls in framed buildings, neglect of soil structure interaction effects, use of inappropriate design assumptions, incorrect choice of construction materials and faulty construction.

Experiences have also taught us that even the structurally safe buildings may collapse if their foundations sink, tilt, uplift, and move down a slope. Such foundation failures may also be contributed by liquefaction of the underlying soil deposit, inadequate foundation, dramatic subsidence of foundation due to collapse of soil-structure of filled-up areas, inappropriate choice of foundation and shoddy foundation construction.

6.7.4 Landslide vulnerability of building foundations is an issue on which there is lack of sensitivity, absence of initiative and subdued professional appreciation. No amount of retrofitting of a superstructure can render a building safe if its foundations or the slope on which it rests are vulnerable. Landslide safety of critical facilities like hospitals, police stations, schools etc must be ensured under the worst combination of forces including an earthquake tremor. Construction of all new critical facilities should be design safe against multiple hazards including landslides. Mainstreaming disaster risk reduction in this way would assure not only that the all critical facilities serve a disaster reduction function, especially when needed the most. Government buildings, hospitals, schools, archeological monuments, dams, highways, bridges and commercial establishments are critical to national economies and compete for priority depending on their relative importance in a given situation and the degree of seriousness of the landslides affecting the area.

The Framework for Landslide Management

Approach and Investments in Landslide Management depend on degree of hazard, vulnerability, the associated risk, and the perceived impact of the risk. The degree of hazard, risk and vulnerability in any given case keep growing steadily with the passage of time with increasing human intervention, neglect of slopes and degree of unpreparedness. The impact is seen in terms of the nature, magnitude and spread of landslide damage. An arbitrary scale (the barometer) of landslide hazard is proposed in Figure 19.

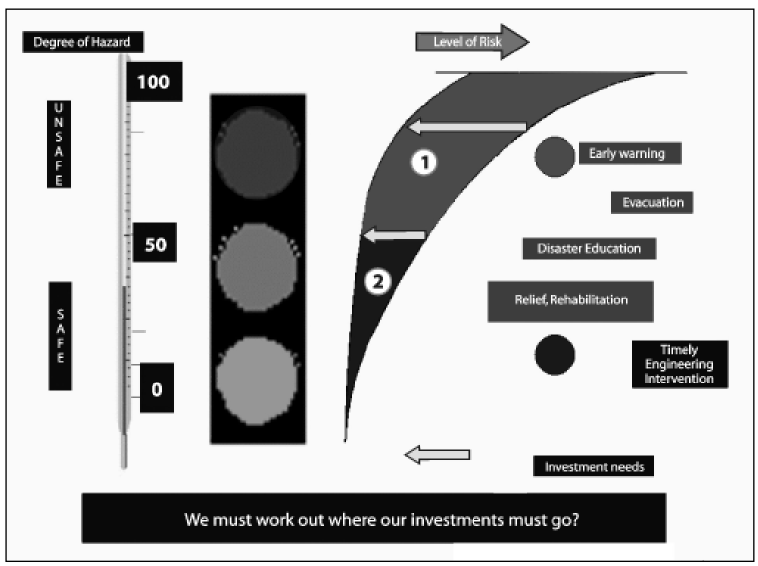


***Figure 19**: Engineering interventions are affordable and effective when landslide problems are small and new (blue zone). Investments on preparedness for evacuation and quick response become inescapable when hazard and risk levels are high (red zone). (Courtesy: R. K. Bhandari)*

A slope free from landslides is labeled as "unquestionably safe" or "safe" (0 percent hazard) at the lower end of the scale and the one affected by a major landslide is labeled as most dangerous (100 percent of hazard) at the upper end of the scale, with the whole range of hazard levels in between. If a slope is already unsafe, and continues to be neglected, it is eventually bound to turn 'dangerous', or even 'most dangerous' driving the situation to more or less a point of no return. On the other hand, the reverse of this could also be true if the unsafe slopes get timely attention, and appropriate engineering interventions are made with a view to putting them back on the path to safety. The cost of remediation, as would be expected, is usually small when the magnitude of the problem is small. By making small orders of investment in remediation and upkeep of slopes, a reasonable degree of safety could be restored to the slope. On the other hand, the engineering interventions will be prohibitively expensive and very different in character if the areas in question have already moved into the dangerous zone. Even with large investments in slope safety in such cases, the risk can seldom be eliminated.

From the techno-economic point of view, most important is the zone of productive engineering intervention or so called "reversible zone". In this zone, landslide problems qualifying for engineering intervention are tackled most cost-effectively, provided timely, appropriate action and the adequacy of resource inputs are ensured.

Integration of Land slide Management with Development Planning

National Plans must highlight the merits of and advocacy for Integration of landslide management with development planning. This would, inter alia, involve seeding the concept of landslide prevention, and opportunity costs in administrative management of landslides; switch over from piecemeal remediation of landslides to holistic implementation of control measures; management of change from outmoded approaches in landslide remediation to state-of-the-art technology based landslide control; empowerment of multi institutional multi disciplinary teams; mobilization of Private sector and Insurance sector participation; change over from conventional bureaucratic benchmarking and project progress evaluation to peer centric progress review, evaluation and mid course correction. New concepts usually tend to breed delay. It is therefore imperative that every country creates a vibrant network of agencies and knowledge based institutions dealing with landslide studies for effective implementation of national landslide agenda and streamline procedures for speedy funding of priority/fast track projects.

Every project in any landslide prone area will have to be so designed as to integrate landslide concerns with holistic planning. Objective criteria and legal instruments will have to be put in place to ensure that no project adds to hill slope instability and Landsliding, both in the short and long run. Where ever constructions have to take place for over-riding reasons, pro-active slope protection works would constitute an integral part of the project design and approval.

Multi-hazard Threats-The big picture

Wherever landslides constitute an element of a multi hazard situation, action plan must include built in environmental preservation and disaster mitigation features in tune with the philosophy of mainstreaming mitigation measures into development projects. There is a need to develop and introduce project formulation guidelines insisting on submission of well considered and peer reviewed projects with clear statements on how multi-hazard disaster mitigation features are woven into the fabric of the project and what limitations or data gaps continue to exist either because of insufficiently developed knowledge base or because of the complexities and uncertainties associated with a given situation.

Most landslides, when small and repetitive, are preventable through timely engineering intervention and sound slope maintenance practices. Landslide risk reduction and landslide management framework should therefore be anchored to the bedrock of the culture of strategic planning and landslide prevention. Wherever it is not possible to prevent a landslide, especially when it occurs first time or is induced by an earthquake, the culture of quick response should take over. The best way to prevent landslides is to recognize slope safety as an integral part of a project design. Clearances of all projects must recognize this requirement.

Lessons from landslide disasters could be learned only if the landslide management framework is made friendly to the scientific spirit of enquiry and pre-determined dedicated multi-disciplinary teams of experts are authorized timely access and funding to study and document disasters. The team of specialist to be engaged in the post mortem should be made familiar with the framework and its obligation in advance so that best efforts could be made avoiding opportunity costs by recording evidences before they get erased.

Landslide Disaster Management Plan

A landslide disaster management plan, at any level, will essentially be a subset of the holistic Disaster Management Plan (DMP). Since a holistic DMP is expected to take care of multi-hazard situations, it follows that response to a landslide disaster will recognize difference between dealing with isolated cases of landslides and those occurring in league with other types of disasters, for example, earthquakes and river floods. Disaster Management Plans drafted at national, state, district and project levels should include all aspects of landslide management including tasks to be undertaken before, during and after a landslide.

DMP should outline the landslide response mechanism with clearly defined roles and responsibilities of various stakeholders including the Government, private sector, voluntary organizations and communities. It should be sensitive the available resources, equipment and capacities as well as to the operational institutional mechanisms so that the capacity could be leveraged, strengths could be synergized and resources could be pooled in good time.

The past history of a slope or a landslide provides very useful clues for its efficient management. Landslide Knowledge Network should be established, strengthened and linked with SAARC Disaster Knowledge Network.

Operational Issues

- Creating a vibrant SAARC Landslide Database as a subset of SAARC Disaster Knowledge Network
- Institutionalization of SAARC Landslide Database management for sustainability.
- Sharing of experiences in integration of landslide management in project development planning.
- Sharing of best practices demonstrating switch-over from piecemeal remediation of landslides to simultaneous and holistic implementation of control measures
- Contribute to global state-of-the-art and to the technology based landslide control
- Joint strategy to mobilize Private sector and Insurance sector participation.

Administrative Issues

- Encouraging SAARC sponsored joint landslide project implementation and monitoring including writing of handbooks and manuals
- Streamlining of procedures for speedy funding of joint priority/fast track projects
- Switchover from conventional project progress evaluation to peer-centric progress review, evaluation and mid-course correction.
- Seeding the concept of landslide prevention, and opportunity costs in administrative management of landslides.

Main Areas requiring Capacity Development

Capacity building is the backbone of landslide risk reduction. It is another name of institution building and purpose oriented networking with shared vision of transforming the current piecemeal, adhoc, less recognized and poorly appreciated landslide management practices to an integrated multi-hazard approach of disaster management. Enhancement of expertise and capacities of knowledge centres in different SAARC Countries in selected key areas such as geomorphological, geotechnical and hydrogeological investigations and for scientific design and speed- effective- implementation of control measures using new technology seem essential. A few such institutions could be handpicked for giving impetus to joint projects and programmes based on shared experience, pooled resource and leveraged capacities.

Scientific Investigation of Landslides

Scientific Investigation of a slope or a landslide falls in a multi-disciplinary domain in which engineering geologists and geotechnical engineers play very important and highly inter-related roles. A sound geotechnical investigation (followed with a sound data analyses) is fundamental to the whole range of tasks from slope characterization to slope engineering. No good slope geotechnology is possible without good hydro-geological, good seismo-tectonic and good anthropogenic inputs in slope analyses. The slope geotechnology therefore embraces a huge expanse and specialized scope of the coverage. A landslide investigation team will naturally be regarded as incomplete without an experienced engineering geologist and an equally experienced geotechnical engineer. Workshops and training programmes should be organized to make professionals aware of the vast scope of geotechnical intervention in landslide studies.

For landslide investigation and mitigation, one needs to map landslide hazards and create a knowledge /database with the fullest appreciation of the scale and degree of reliability of the information gathered. For estimation of destructive potential of a landslide, one needs to know its expanse/spatial extent and also time scale of landslide activity, mechanism, runout distance, elements at risk enroute and its recurrence history. For prediction of a landslide one needs to find out where it will occur, when will it occur and how far and how fast will it move? For design of control measures to manage landslides, one need to know what the landslide type is (its classification), what could be different possible modes of failure, where its slide boundaries are, what the operating shear strength characteristics of boundary shears are and how the pore pressures will vary on the slide boundaries with time. For measuring the efficacy of control measures, one would need to know the actual performance of the slope measured vis-a-vis the design performance. The plan of geotechnical investigation should clearly state the purpose of geotechnical investigation.

Figure 20: *Visual evidence of discrete boundary shear at the Watawala Earthslide in Sri Lanka. (Courtesy: R. K. Bhandari)*

Broadly speaking Geotechnical Investigation of a landslide include mapping of problematic slopes on an appropriate scale, scientific understanding of its kinetics, elucidation of landslide boundaries, determination of representative shear strength parameters and pore pressure variations on the slide boundaries and finally evaluation of factor of safety. Undisturbed sampling and determination of representative shear strength parameters on slicken-sided slip surfaces (Figures 20 and 21) are daunting tasks in geotechnical testing. It is important to understand the distinction between the first time and the reactivated slides. The boundaries of the first time slides are not known in advance. Also the investigation needs and mitigation measures for a possible landslide (which has not happened but which may happen) may be different.

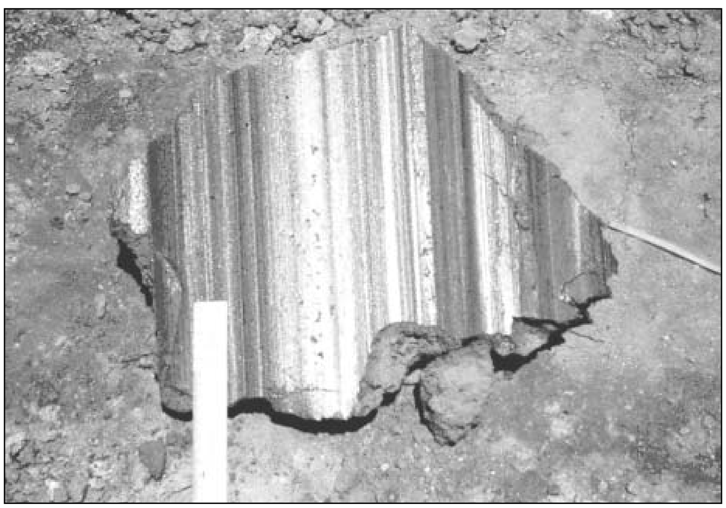


Figure 21: *An excellent example of the striated and highly polished and slicken-sided slip surface observed in the undisturbed sample from the basal slip surface of the Watawala Earthslide in Sri Lanka. (Courtesy: R. K. Bhandari)*

Geotechnical Investigation for mass movements like rapid motion landslides, multi-tier landslides, rockfalls, debris flows and avalanches may throw up many other investigational requirements. Then there could also be cases of landslides changing their character. For instance, in its wetter manifestation, a landslide may partake the character of a flow and acquire rapid motion. In such cases laws of fluid dynamics may take over from the laws of classical soil mechanics. Workshops should be organized to train geotechnical engineers in the art and science of such investigations.

A good geotechnical slope investigation is usually driven by the leads thrown up by the large scale geomorphological map of the area. It should always begin with careful study of field evidences that usually lie at the doorstep of a trained landslide investigator. For instance, study of the slide boundaries, exposed geology, discontinuities, shear zones; water springs, aquifers, slope subsidence, heave, cracks and behaviour of buildings, etc., provide a sense of direction to the nature and quantum of ensuing detailed sub slope geotechnical investigations. A vigilant eye can express much more by looking at an exposed roadside cutting than the whole gamut of geotechnical investigation could ever reveal even at a huge expense of time and money. No amount of drilling, regardless of its quality or quantity, can ever replace the clarity with which one could log the world of fissures, the character of slip surfaces and shear zones, the nature of gouge material in the joints, the erratic nature of soil profiles, the sand and the silt lenses, the solution cavities, the evidences of underground erosion and more, visually seen in the open exposures and cuttings. Guidelines should be developed and appropriate codes of practices and skill development programmes will be evolved to ensure that every formal clearance for geotechnical investigation proposal is based on such a planning approach that makes use of hard field evidences and seek answers to the questions thrown up by the field evidences. No matter how thorough is the geotechnical investigation, uncertainties involved would always call for making design assumptions based on engineering judgment. Every geotechnical report must clearly state the assumptions made and the basis there of.

It would therefore be a big mistake to prescribe a rigid programme of soil investigation at the outset. The best soil investigation programmes are those which advance and get modulated with every shred of new investigational information. Blind recommendations on number of bore holes, their locations, undisturbed sampling and insitu testing should not be allowed.

A Geotechnical Investigation often tends to get expensive and even wasteful if it does not relate closely to the slope information to be gathered and the specific questions to be answered. For instance, it has become a common (mis-)practice to prescribe an extensive programme of drilling to locate basal boundary shear of a landslide even without a site visit. One must remember that even with extensive drilling, the basal boundary of a landslide may defy attention in the core logs. Imagine the savings and time effectiveness in investigation that will accrue if one were to succeed in locating traces of basal boundary shears in, for example, a road side cutting.

Selection of equipment for slope investigation, drilling and in situ testing and decision on scale, scope and type of undisturbed sampling and laboratory testing are highly specialized matters. The present tendency of making divergent un-informed choices without adequate scientific reasoning must end. There is a need to develop guidelines on this, especially for the training of geotechnical engineers engaged on landslide projects as also for the benefit of those responsible for building institutional capacities. Private sector can play a major role in improving national capacity on quality geotechnical investigation and will be encouraged through professional bodies.

Deterministic analyses of slopes can be either two dimensional or three dimensional. Two dimensional analyses under-estimate the factor of safety and are therefore done where either side resistance to landsliding is negligible or uncertainties are large and quick conservative designs are required for further planning. For important projects where high quality investigation is mandatory, a three dimensional analyses should be done for ensuring economy in design. Since there are uncertainties involved at various steps of investigation and design, and it is not always possible to justify single value inputs, the need and merit of probabilistic analyses of slope must also be considered.

Deterministic analyses could either be in terms of effective stress or in terms of total stress. The unhealthy practice of ignoring this essential requirement must stop. There is a need to develop guidelines on two and three dimensional stability analyses of landslides and other mass movements and highlight implications of assumptions made and limitation of the findings. The guidelines must clearly focus on hitherto neglected but vital aspects such as techniques of undisturbed sampling of shear zones and boundary shears and evaluation of shear strength parameters using appropriate stress path. It is often meaningless to spend money doing tests such as SPT and DCPT in drill holes or unconfined compression tests in a laboratory. Since shear strength is not a unique property of a soil sample, laboratory tests without obtaining representative high quality undisturbed samples and without picking the right type of test could also be misleading. Besides above, one must remember that soils are non-homogeneous and anisotropic and their non-linear behaviour is greatly influenced by its stress-strain history and structure. We need geotechnical guidelines to cover this aspect adequately.

Most landslides being the result of poor slope and sub slope drainage, detailed hydrological studies of the catchments associated with landslides are essential. In the areas of complex landforms with water streams, springs and ill defined overland flow; radioisotope studies are often useful to map subterranean water flow while investigating the causative factors of a landslide.

For the ultimate objective of an investigation to be achieved, the coupling between study of landslides through remote sensing such as by satellite imageries and ground surveys of the very landslides should be logical and strong. Landslide investigation without remote sensing is often blind. By the same logic, landslide investigation without ground studies and validation is lame.

Geotechnical investigation of landslides, which in their wetter manifestations partake the character of a flow, calls for different kind of investigation. In most such cases the laws of fluid mechanics tend to take over from the laws of soil mechanics. The major difference lies in short-lived nature of slip surfaces and kinetics of the mass movement. The classical method of slope analyses or back analyses no longer remains valid.

Landslides in metastable deposits of granular (sandy) nature, especially in the high rainfall areas, tend to liquefy due an earthquake shock or external vibration generating flow slides. Similarly earthquake-induced landslides could be co-seismic or post-seismic. Geotechnical investigations for such set of problems fall in a highly specialized domain and must be referred to a team of experts.

Reference to geotechnical reports prepared for different civil and infrastructure development projects at or close to the location of a landslide will serve the triple purpose of consolidating the available body of geotechnical information, pinpointing the inconsistencies, inadequacies and gap areas and provide a cost-effective and sound basis for deciding the geotechnical scope of a landslide investigation.

Promotion of the culture of observational method of design and construction

It seems to have become a common practice in landslide management to present an oversimplified picture of a landslide that has little resemblance to the truth about the actual mechanism of slope behaviour. Observational method of slope engineering design and construction is a versatile answer to dealing with uncertainties, especially in slope investigation and characterization. It allows engineers to monitor slope behaviour during construction so that designs could be altered on the basis of actual field observations as the work progresses.

Uncertainties on account of aleatory (inherent) factors like dynamics of spatial variation of pore water pressures are understandable. Epistemic uncertainties due to instrumentation and human limitations during landslide investigations are also understandable. What is really unacceptable however is the remediation and management of landslides, ignoring the need for scientific investigation and reliable diagnosis.

All major landslide control projects should take recourse to observational method of design and construction incase investigations are not thorough enough to lead to reliable diagnostics.

Early warning against landslides

In a holistic sense, the term early warning includes the whole range of actions and operations right from planning and instrumentation of problematic slopes and landslides to their monitoring, analyses, fixing of early warning alert thresholds, decision making, dissemination of early warning alerts and recurring improvements in early warning practice through sustained location-specific feed back and new researches. Projects aimed at early warning against major landslides should be encouraged taking advantage of the fact that, unlike many other disasters, early warning against a landslide is possible at the present state-of-the-art. An example of the first wire actuated early warning system at the site of Berahgala landslide in Sri Lanka is shown in Figure 22.

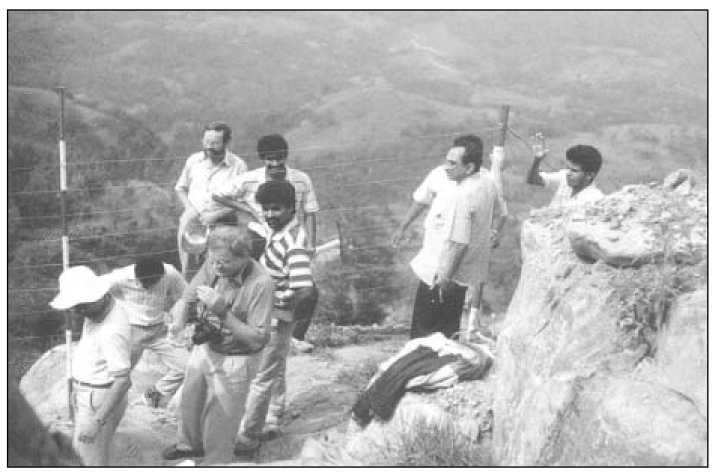


Figure 22*: An early example of a simple wire-actuated early warning system installed at the Viharagalla landslide in Sri Lanka.(Source : NBRO, Sri Lanka)*

There are no standard ready-made packages or systems for early warning but systems are to be designed based on the geotechnical situation faced. All the instrumentation, tools, equipment, observation and data processing systems are available in multiple choices. They are necessarily to be fashioned to suit a particular slope or a landslide according to its type, magnitude, importance of a landslide and the purpose of early warning alert. The hazard detection and early warning systems for different types of landslides are also usually different. For example, planning for instrumentation and early warning for a pre-existing (repetitive) landslide will be very different from the schemes for early warning against anticipated first time landslides. Likewise early warning schemes for mass movements such as a debris flow or a rock fall will be very different from those for a block side or a classical landslide with discrete boundary shears. The task of evolving early warning system in a given situation will necessarily have to be assigned to a team of experts.

It is a wrong notion among non-professionals that early warning systems for slope failures and landslides are always sophisticated and expensive. The fact however is that in many situations, simple, in expensive and easily measurable indicators can provide premonition of an impending slope failure. Monitoring of rainfall, surface and sub slope movements, slope subsidence, slope heave, development and widening of cracks, tilting of trees and poles, sudden oozing out of water or drying of water springs, sub slope piping and under slope erosion, sudden fall of boulders, cracking of building floors and such other happenings often provide irrefutable evidences of unsatisfactory slope behaviour. Randomly picked, isolated observations of this kind don't convey much but when all such evidences are a pieced, analyzed and connected with other inputs, early warning alerts become possible. Guidelines and Field Manuals should be written and workshops and training programmes should be organized for different target groups. Full scale SAARC projects should be encouraged to create pace setter examples of early warning as also for training of professionals on the projects.

Simple devices commonly used for early warning against landslides in the past are (1) wire or special switches, actuated by the pressure of moving debris coupled to a decision-support system that release early warning alerts (2) electrical switch poles – which turn to an upright position upon displacement (3) photo electrical barriers, especially for a rapidly moving debris flow or earth flow (4) pulsed radar for snow avalanches (5) fiber optic sensors and technology (6) acoustic emission technology (7) auto-actuated photographic systems and (7) GPS observations. Projects should be encouraged to develop and effectively utilize these devices further to facilitate quality monitoring in a cost effective manner, aiming at real time early warning.

A great majority of dormant landslides often turn active and violent during the monsoon season and high intensity short duration rainfall events are generally held responsible for triggering such catastrophic landslides. This single observation is enough to underscore the importance of reliable and continuous rainfall measurements and real time analyses of rainfall data preferably at all major landslide sites.

While it is true that early warning thresholds cannot be standardized, it is equally true that no early warning can be given without fixing early warning thresholds. The complexity in fixing early warning thresholds generally arise from a number of factors such as uncertain quality and inadequacy of instrumentation and information on the landslide (quality of investigation and quality of analyses), great variability in the type of a landslide (for example, a slide, a flow, or rock fall), lack of clarity about its nature (first time, repetitive or multi-tier), the purpose of early warning (regulating the traffic on a road, timely stoppage of a railway train, safety of people on the problematic slope etc) and the difficulty of quantifying the importance of elements at risk (a residential township, an isolated building, a bridge linking two important cities, a heritage structure etc). The answer lies in assigning the task of fixing early warning threshold for a given landslide to a team of experts aiming to relate the thresholds to the art of decision-making under uncertain premises, on a case to case basis. It follows that early warning thresholds for a landslide would be different; if in one case it involves sinking of a road or a railway line and in other case when the same slide supports a township or human settlements. Large vertical and lateral deformations of roads or railway lines are often taken care of through periodic maintenance but human settlements will be sensitive to small orders of ground deformations threatening human life. Awareness programmes are necessary to educate the public on the limitations of early warning. Investments on research and development work on some selected landslides would help to enhance the credibility of early warnings.

Rainfall information should be utilized for developing indicators for landslide alert especially for high landslide hazard areas known to succumb to cloud bursts and high intensity short duration rainfalls. Early warning threshold for a well studied seasonal (repetitive) rain-induced landslide on discrete boundary shears with known pore pressure variations on the slide boundaries are most reliable. Such early warning thresholds usually take advantage of the unique, linear relationship between Factor of Safety (in terms of effective stress) and the pore water pressure (considered in terms of ratio ru). Since inter-relationships between rainfall intensity, slope surface and sub slope movements and pore pressures provide powerful means for reliable landslide forecasting, these should be encouraged. In cases where no such information is available, a warning of a general nature and low reliability may still be possible through study of rainfall records in the back drop of the previous landslide history.

Prediction of Landslides is possible and research and development work on it deserves to be encouraged. Attempts to predict landslides have so far been based on time-dependent displacement behaviour of slides generally in the tertiary stage of tertiary creep. Increasing availability of high-resolution geospatial maps and powerful slope instrumentation techniques create real-time prediction of landslides possible. Research and Development projects on prediction of landslides should be encouraged within and between the SAARC countries.

Once a decision for early warning is taken based on available information inputs, the early warning dissemination strategy could be common to that prescribed for other types of disasters. Operations such as post early warning interfacing with communities, press and media are common to all types of disasters. Integrated early warning dissemination systems should be evolved.

Even with the best of early warning systems, results will still be catastrophic if early warning signals are not properly interpreted and communities are not educated and trained on how to respond to the early warning alerts in real time. There should be an easily understandable manual clearly bringing out what to do incase an early warning system flashes such an alert. Quite often the early warning alert may be lost in panic and confusion, if people are not aware of the response that must follow such alerts.

Early warning messages (text, graphics and, sound) transmitted through various possible means (such as Government circulars, radio, internet, press and media) need to be simple, unequivocal and easily understandable by the people even under heightened stress. This will call for specialized training programmes on drafting and decoding of early warning messages and their scientific interpretation and timely action.

Landslide Education at all levels

Landslides are nature's safety valve and inevitable happenings witnessed by the mankind over centuries. We would not have had fertile planes but for landslides. The only difference then and now is that landslides tend to be more a manmade rather than a natural phenomenon and mainly we are responsible for landslides turning into landslide disasters. The buildings we build trigger landslides and landslides in turn retaliate to destroy buildings. Since they affect safety of people at large, naturally landslide education too must spread to the grass roots level.

Our children must be made to distinguish between the beauty of a natural landslide and the ugly face of a man made landslide and they must be taught to oppose violence against our mountains. Our school teachers should be made aware of their crucial role as what they teach in the class invariably leaves an indelible mark on the mind of a child. We need to educate our professionals who practice landslide management for they generally display a huge gap between theory and practice of slope engineering

Anthropogenic factors fuel landsliding and that needs to be underscored in the education of our architects, planners, engineers and builders. Landslide education for professionals should be accomplished through revision of syllabus, enlarging the scope of teaching earth sciences and allied disciplines and through crafting of new educational programmes. The curriculum in earth sciences, engineering geology, seismology and geotechnical engineering, structural engineering and architecture needs special attention. Another area needing intervention is training of professional engineers and architects to ensure that new technology benefits professional practice. A large number of professionals require training and retraining. Unfortunately quality teachers, quality text books, quality training kits, etc. are not available for landslide education and these can and should be developed for the SAARC region as a whole.

Professional education in some selected areas deserves emphasis if we are to overcome the lack of appreciation in getting the pathology right before the problematic slopes could be treated to safety. Geomorphologists will have to perceive macro geomorphology and use it in slope analyses to send across a message that present practices of dismembering slope into factors such as relative relief and slope erosion, without a macro view, could be misleading. Engineering geologists will have to discuss micro geological details controlling a landslide, and not just stop at the broad description of lithology. A geotechnical engineer needs the education to realize that the orthodox soil mechanics has long been replaced by modern soil mechanics arming him with concepts, tools and techniques that can help characterize and analyse landslide reliably. The landslide managers need the education that they should insist on a scientific, systematic slope investigation and that adhoc measures without sound investigation may prove to be a costly waste.

Education of in service professionals would need considerable unlearning because many of them did not have time, opportunity or pressure of updating their knowledge. Self education programme by effective use of multi media based knowledge products need encouragement and priority.

The thrust areas for Training of Teachers and Trainers

- Geomorphological, Geotechnical, Hydro-geological and GIS based Landslide Hazard Mapping with perception of Mapping Scales.
- Geotechnical Investigation of Landslides with particular reference to characterization of slopes, elucidation of landslide boundaries, representative undisturbed sampling from shear zones, handling of samples, simulated stress-path testing and stability analyses in terms of total and effective stresses.
- Techniques of monitoring slope surface and sub slope movements and movement rates and cross linkage with rainfall record, piezometric profiles and behaviour of buildings and structures on the slope.
- Slope Modeling
- GIS based Landslide Hazard, Vulnerability and Risk Assessments
- Slope Kinetics, Site Effects and Earthquake Induced Landslides in seismic microzonation and Risk Assessment
- Retrofitting of Structure-foundation-slope systems in areas prone to landslides and earthquakes.
- Instrumentation of slopes, landslides and avalanches, and early warning.
- Design of landslides and avalanche control measures with particular reference to choice of technologies
- Training of first responders in search, rescue and medicare
- Training of Communities and Local Bodies
- Training for visual and print media in the science and art of landslide management for improved and more objective reporting.

Public Awareness and Community Leadership Development

Well informed communities are the best insurance to achieve reduced vulnerability to all forms of disasters, and landslides are no exception. Spreading of public awareness and education is the key to the spreading of the culture of safety. It is important that the Governments, in collaboration with knowledge institutions professional bodies, and other stakeholders make efforts to equip communities with the answers to questions listed below:

- What are the major disaster threat perceptions m the localities of immediate concern to them, and what are the projected likely disaster scenarios (landslide included)?
- What are the possible landslide hazard distribution scenarios and major known landslide spots and identified elements at risk in the area?
- What are the lessons to be learned from the past landslide disasters in the areas and from their (mis) management?
- What are the precursors and early indicators that can avert landslide disaster?

- What are the elements like roads; schools etc exposed to landslide risk?
- What is the role and responsibility of the Government and local bodies before, during and after a disaster?
- What are the expected roles and responsibilities of communities and people at large before, during and after a disaster?
- How much responsibility does the residents and communities are willing to assume in choosing to live or do business in high risk areas?
- What is the role of public sector, NGOs and other voluntary organizations?
- Although it is builders' responsibility to ensure that the construction materials, design and construction conform to prevalent building codes and establish engineering practices, to what extent is the local Government responsible for training urban planners, architects, engineers, builders, property owners etc on issues connected with cataclysmic landslide events.

The Culture of Quick Response

The culture of quick response showup in timely early warning and disaster management according to a plan. For quick response to a landslide disaster, the Disaster Management Plan for the case in point must provide for the specific needs of landslide disaster management. An efficient relief and rescue operation makes it imperative that both trained manpower and essential equipment are either ready at hand or within easy reach.

Thrust of Research and Development

- Revisiting of past major landslide disasters for scientific post-mortem and documentation of lessons learned.
- Refinement of approaches to GIS based landslide hazard mapping, vulnerability, risk, impact and damage assessments.
- Integration of Landslide hazards into user-friendly multi-hazard mapping. Projection of multi-hazard risk scenarios.
- Fundamental mechanisms of earthquake- induced and earthquake-triggered landslides.
- Establishing best practice examples of Deterministic and Probabilistic stability analyses of complex natural and manmade slopes and landslides
- Scientific design of surface and subsurface drainage systems, technology for their speedy installation and field evaluation of their efficacy
- Development of innovative technologies for landslide control, especially mechanized construction of complex subsurface drainage networks and their critical evaluation.
- Quantification of environmental degradation, cost of loss of land and agriculture produce and of traffic delays
- Retrofitting and protection of heritage buildings in landslide prone areas
- Development of simple and easy to install instrumentation and slope monitoring for real time early warning including early warning thresholds and criteria
- Study of landslide dams and management of consequent threats
- Reservoir induced seismicity

- Fashioning landslide rescue operations to their typology
- Snow avalanches
- Coastal landslides
- Submarine slumping and tsunami induced landslides

Landslide Knowledge Management

Efficient landslide management will require information in useable form which may vary from one case to another. In view of huge uncertainties, often subjective judgment becomes inevitable. Equally important is, therefore, the strategy for landslide knowledge management. Data sharing amongst the various knowledge institutions is an even more important aspect and needs to be addressed. Information of practical value generated through all Government funded projects should be treated as national asset and should be freely made available. This will not only ensure that critical data will be available at the time of any disaster but also ensure that there is no avoidable duplication of the effort. This is an area in which any joint initiative by the SAARC countries will pay the highest dividend.

Fiscal Incentives and Insurance against Landslide Hazards

Fiscal measures like rebates on income and property tax for retrofitting buildings on unsafe slopes, compulsory risk insurance for bank loan on all types of properties etc shall definitely help to mobilize resources for safe constructions and retrofitting of existing constructions in all disaster prone areas. Similarly many innovative measures may be taken for promoting public-private-community partnership for disaster risk reduction. Insurance distributes disaster risk among the broader sections of society, thereby reducing it to an acceptable level. Insurance companies should distinguish between Human settlements and infrastructure on well maintained slopes and those already under threat to their safety while deciding on the premium. Since most people are not in a position to pay insurance premiums even when pitched at a modest level, innovation in insurance sector is necessary to launch group insurance schemes and schemes which take care of the premium at the stage of development and construction.

Concluding Remarks and Salient Points for Discussion

A few other topics will justify higher priority for regional cooperation between the SAARC countries than landslide risk management. For decades, all the member States of SAARC (with the only exception of Maldives) have suffered staggering losses due to landslide disasters. If one were to assemble the wealth of information and experience generated in the process, our knowledge will suddenly expand several fold. And if and when this knowledge and experience could be put to effective use, we may be able to avert many of the landslide disasters otherwise waiting to strike us in the future.

The background paper aims at a SAARC Roadmap for effective landslide risk management. Such a roadmap can be evolved only through discussion between the representatives of member States and through cross fertilization of ideas. Whereas the workshop will create the right platform for discussion, this background paper is meant to offer a menu of topics and ideas worthy of attention, to pick and choose from. Since the scope of possible coverage is huge, it is a daunting challenge to be selective and focused. National priorities continuously evolve amidst paucity of resource which is why commitment of national Governments for sustenance of effort is crucial for success. The proposed workshop is expected to deliver an Action Plan sensitive to priorities within priorities, which should also be doable.

Of the various strengths to drive the SAARC landslide risk reduction programme, the most noteworthy is the assurance of political will at the highest level reflected in the Disaster Management Apparatuses of the SAARC member States. With the improved clarity of the national programmes, any regional programme to be undertaken at the SAARC level supplement and complement national initiatives in order to add value and hasten up the process. Formulation of policies, forging appropriate operational strategies, drafting of disaster management action plans, ordering of priorities, launching of national programmes, deployment of resources etc are the responsibilities of the respective national Governments. Regional programmes will therefore be only in those areas in which the cause of landslide risk management will better flourish through regional initiatives.

One would naturally expect SDMC facilitate action, because it is precisely the purpose for which it is created. Also, there are problems SAARC countries cannot solve alone but collectively the solution may be well within their grasp. Programmes carried out under the aegis of SAARC will also lend added weight due to synergy of response to the international commitments of member states; the Tokyo Action Plan or the Hyogo Framework of Action are two examples.

The background paper, inter alia, has provided a snapshot of landslide problems in south Asia. It highlights number of topics worthy of discussion at the workshop. Some of the suggested action points are given below. The list is not exhaustive, and naturally more ideas will emerge during the course of discussion.

Establish a unified Terminology and Landslide Classification System for adoption by the SAARC member states for achieving a common language to facilitate scientific exchange of experience, and more effective regional and international documentation and communication of landslide related studies and data.

Develop Guidelines on Landslide Hazard Zonation, Vulnerability and Risk Assessment for adoption by SAARC member States. Inter alia, the Guidelines should reflect on the Approach and Methodology for Landslide Hazard mapping based on the experiences of member States and on lessons learned from the ongoing hazard mapping programmes.

Publish thematic SAARC knowledge products on the regional dimension of hazards due to Landslides and other Mass Movements. Examples:

- A Monograph on Major Landslides of South Asia. Participating Countries could be Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka. This will not only serve as a scientific record of cataclysmic landslide events for posterity but, equally importantly, will be a very useful knowledge product for promoting landslide research, education and training.

- A Monograph on Glacial Lake Outburst Floods in South Asia. Participating Countries could be Afghanistan, Bhutan, India, Nepal and Pakistan. Inter alia, it will help focus national, regional and global attention on rapidly building threats due to GLOF
- A Monograph on Technology for Search and Rescue for improved response to Landslide Disasters. All SAARC countries can participate.
- A Monograph on Landslide Damage Assessment. All SAARC countries can participate.
- A Monograph on retrofitting of slopes and houses in landslide and earthquake prone areas. All SAARC countries can participate.
- Guidelines on Geological and Geotechnical Investigation of Landslides. This is identified as very poorly developed area in the entire developing world.

Launch a SAARC Programme on Landslide Prediction and Early Warning. All SAARC countries can participate. Various possibilities can be examined. For instance:

- Carry out a multi-institutional project on development of Approaches and Methodologies for Early Warning. This could be based on slope analyses, modeling, instrumentation and real time monitoring.
- Draft Guidelines on Community Based Early Warning against Landslides using simple indicators such as visual observations on the slope and surroundings, rainfall data and so on.

Develop approach to include the considerations of earthquake-induced landslides in assessment of hazard, vulnerability and risk. All SAARC countries can participate. The high importance of this topic is obvious because earthquake-induced landslides severely hamper post earthquake relief operations.

Undertake writing of books, manuals and materials for education and training on diverse aspects of landslide management including those for school children, public at large, training of trainers and teachers.

Establish a Landslide Disaster Knowledge Network as a vibrant component of SAARC Disaster Knowledge Network. All SAARC countries can participate. This may eventually lead to publications of (a) SAARC Newsletter on Landslides (b) SAARC Journal on Landslides.

Establish a SAARC Regional Centre of Excellence on Landslide Studies, Education and Training. It may be recalled that International Consortium on Landslides was established in 2002 at the Kyoto Symposium on Landslides held in January 2002 and is supported by organizations such as UNESCO, WMO, UN/ISDR and FAO.

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***Annexure1**: Some recent landslides in South Asia*

Date	Location	Deaths	Injuries	Property damage
AFGHANISTAN				
04 May 07	N. Afghanistan	1	1	-
July 07	Takhar	8	-	-
July 07	Kunduz	6	-	-
BANGLADESH				
11 July 07	Chittagong	91	150	-
03 July 07	Teknaf and Ukhia Cox's Bazar district	19	-	-
14 July 07	Himchhari, Cox's Bazar district	2	-	-
30 Mar 08	Village in Siah Gard district, Central Parwan Province	-	-	36 house destroyed
06 Mar. 08	Qalae Girdab village of Rustaq district, Northern Takhar Province	6	-	150 sheep and 30 cows died
BHUTAN				
14 Sept. 07	Chukha dzong	2	-	-
BANGLADESH				
03 July 08	Teknaf and Ukhia upzilas, Cox's Bazar	10		-
04 July 08	Chittagong	-	2	5 houses damaged
06 July 08	Kalyanpara in Teknaf upazila of Cox's Bazar	4	-	-
14 July 08	Himchhari, Cox's Bazar	2	-	-
22 July 08	Kalo Pahar in Sunamganj	-	10	About 100 homes destroyed and covered around 100 acres of land
18 Aug 08	Motijahra Hossain Colony, Chittagong	14	-	-
INDIA				
27t Feb. 07	Panthal, Jammu Srinagar Highway	---	---	Highway blocked
18 March 07	Doda, Jammu and Kashmir	2	5	3 houses damaged
24 June 07	Chembur, Mumbai	2	-	-
15 July 07	Kurseong and Darjeeling		-	Two houses damaged
16 July 07	Katahbari, Guwahati	2	-	-
16 July 07	Siliguri, Darjeeling	-	-	Damaged Road
17th July 07	Bardang near Singtam, Gangtok	-	-	Damaged National Highway 31A
20 July 07	Guwahati	7	-	-
28 July 07	Tura, West Garo Hills	9	-	3 houses damaged
30 July 07	Kinnaur	4	Many	-

Date	Location	Deaths	Injuries	Property damage
30 July 07	Chamba	3	-	-
11 Aug07	Chattru, Lahaul Spiti	1	2	-
12 Aug07	Kanga, H.P.	8	-	-
15 Aug07	Dharla, H.P.	At least 62	-	14 house & a primary health care centre damaged
2 Sept 07	Nivsur & Ratangiri	-	-	Konkan Railway Route
6 Sept 07	Pithoragarh	5(9 others feared dead)	-	-
7 Sept 07	Kalimpong, Darjeeling	6	-	80 houses damaged
16 Sept 07	Guwahati	3	-	-
29 Sept 07	Loharkhet, Almora	4	-	-
19 Oct 07	Lalmati Near Kohima	-	-	Road damaged
27 Oct 07	Udhagamandalam-Coonoor, Near Nilgiris	1	2	Many House damaged
17 March 08	Manali, Himachal Pradesh	25		
1 May 08	Kishtwar, J&K	20		
14 June 08	Ranchi	15		
14 June 08	Itanagar, Arunachal Pradesh	14	More than 50 injured	
2 July 08	Mandi Himachal Pradesh	2	1	
18 July 08	Dehra Dun Uttrakhand	10	12	
26 July 08	Chamoli, Uttrakhand	8	2	
21 Sept.08	Nahan, Himachal Pradesh	6		
30 Oct. 08	Itanagar, Arunachal Pradesh	12		Many houses damaged in flash flood
30 Oct. 08	Lakhimpur, Sontipur, Assam	7		
30 Dec. 08	Jammu and Kashmir		6	
NEPAL				
08 Jan 07	Khara area of Darchula district	3	20 missing	-
27 April 07	Saptari	2	-	-
01 June 07	Garagaun in Jharkada VDC	-	-	80 family displaced
10 June 07	Tanahu	2	5	-
13 July 07	Baglung & Bajura	26	17	20 houses buried
13 July 07	Khumjung Village, in Solukhubu District	-	-	14 family displaced
3Aug 07	Siddhartha Highway at Dovan VDC-5	-	-	Damaged highway
03 Aug 07	Belawa-7, Bardiya	1	5	-

Date	Location	Deaths	Injuries	Property damage
13 Aug 07	Baitadi and Darchula	9		40 family displaced Dozens houses damaged
24 Aug 07	Gulmi	6	-	Many houses damaged
25tAug 07	Phythun	5	Many	
missing	Many houses damaged			
31st August 07	Gulmi, Argakhanchi and Banke districts	6	5 injured	-
4th Sept. 07	Palpa and Kalikot districts	5	3 missing	10 houses damaged
6 Sept. 07	Makwanpur district	2	3 injured	
6 Sept. 07	Naubise-Simbhanjyang	-	-	Black Tribhuvan highway
9th Sept. 07	Kaski and Nawalparasi districts	6	120 families affected	-
9th Sept. 07	Ladabhir and Sirthauli VDCs in Sindhuli District	6	100 family affected	Houses damaged
09 Sept. 07	Sarankot village Near Pokhara	4	-	Many houses buried
29th Sept 07	Bhairavsthan VDC and Laghuwa of Deurali VDC	-	-	Damaged road & many houses
20 June 08	Khotang, Nepal			Landslides have post a threat to 250 houses & displaced 20 families.
26 June 08	Dhading, Nepal	4		
23-30 June 08	Kathmandu, Nepal			Displaced about 100 families
07 July 08	Nuwakot, Nepal	2 missing		
13 July 08	Sindhupalchok, Nepal	1	2	
31 July 08	Jajarkot, Nepal	9		
06Aug08	Bajura, Nepal	9		3 house completely destroyed
16 Aug 08	Kalikot, Nepal	6	2	Many houses destroyed
17 Aug 08	Kathmandu, Nepal	2	14	
19 Aug 08	Kalikot, Nepal	8		
21 Aug 08	Kalikot, Nepal	1		According to the local police about, 15 people were killed
31 Aug08	Tanahum, Nepal	5	3	
01 Sept08	Bhojour, Nepal	3	2	Displaced 13 families
20 Sept.08	Palpa, Nepal	10		15 families displaced
26 Dec. 08	Bajura, Nepal	3		

Date	Location	Deaths	Injuries	Property damage
PAKISTAN				
09 Jan 07	Muzaffarabad	15	3	-
27 Feb 07	POK	37	-	-
27 Feb 07	Dir(NWFP)	6	2	-
27 Feb 07	Kashmi, Pakistan & Northern Pakistan	67	-	-
18 Jan 08	Muzaffarabad	2	4	
03 Feb 08	Quetta, Pakistan	6	4	
26 May 08	Mingora, Pakistan	6	1	Rains and hailstorm damaged orchards and standing crops
26 June 08	Rawalpindi Pakistan	3		
15 July 08	Narain, Pakistan			Thousands feared trapped due to landsliding near Kaghan-Narain
6 Aug 08	Gilgit, Pakistan	7		
SRI LANKA				
27 April 08	Ingiriya, Sri Lanka	6		
1 May 08	Jaffana, Sri Lanka			1350 families affected. Many people were killed or missing after landslides buried houses under thick mud across the central Java province this week
14 July 08	Colombo, Sri Lanka	2	5	
23 July 08	Mapitikanda, Colombo, Sri Lanka	3		3 children buried alive. Many houses damaged
5 Sept. 08	Kahamba, Colombo, Sri Lanka	1	1	
9 Dec. 08	Colombo, Sri Lanka	5	10	
12 Dec. 08	Matara, Sri Lanka	1		
29 Dec. 08	Koslanda, Sri Lanka	1		

Geomorphology and Landslide Potential of the Bamiyan Valley, Afghanistan

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Abstract
The present work reports geomorphological and geotechnical investigations carried out in the UNESCO site of the Bamiyan valley (Central Afghanistan) in 2007 in order to reconstruct active deformation processes and geomorphological hazards affecting Cultural Heritage. The site is known worldwide for two standing giant statues of Buddha destroyed by Taliban in March 2001. The geomorphological field survey has reconstructed the main active geomorphological processes along the cliff area mainly related to superficial waters (e.g. erosion, infiltration along joints, accumulation of mud/debris) and slope deformations (e.g. toppling, rock falls, rock slides, jointing). The geomorphological survey has been integrated with geotechnical, structural and kinematic analyses concentrated in 17 distinct sections of the cliff where geological processes were more prominent. This to detect and investigate potential failure modes of the jointed rock masses forming the Bamyian cliff. The kinematic analysis produced different results for the various slope failure modes analysed according to local structural and geomorphological characteristics of the cliff. A geomorphological map reporting the main processes surveyed in the area has been produced.

Keywords: Geomorphology, Slope instability, structural analysis, landslide kinematics, Bamiyan

Geological Setting

The Bamiyan valley (Figure 1) is an intramountainous basin, subsequently filled with debris material originating from the surrounding mountain ranges (Lang, 1971; Reineke, 2006). The Neogene near-horizontally bedded sediments can be distinguished into four strata. Starting with the Eocene Dokani Formation (>80m sandy carbonate and anhydrite) and the Zohak Formation (>1000m red conglomerate), the so called Buddha Formation is deposited in the Oligocene and built up by >70m yellow-brown pelite, sandstone, conglomerate and some volcanic material. The top is composed by the Miocene Ghulgola Formation (>200m sandstone, clay and lacustrine carbonate) and the Pliocene Khwaja-Ghar Formation (ca. 200m travertine, sandstone and conglomerate. The Qal'acah Formation is almost contemporary to the Buddha Formation and reflects a detritic facies on the slope of a volcano (Lang, 1972).

At north and south of the fault lines of the tectonic graben, red clayey soils formed by metamorphic contact can be found. Along these fault lines, volcanic activity can be recognized. This may have modified (fritted) the surrounding sediments and changed their colour into red.

From the late Pliocene to the end of Pleistocene (Reineke, 2006) the Neogene sediments have been incised by fluvio-glacial erosion. Alternating warm and cold periods lead to changing conditions between accumulation and erosion, so that different Quaternary terraces developed.

The cliff and niches have been excavated into the so called Buddha Formation and are composed by alternance of conglomerate and siltstone (yellow at the bottom and red in the middle of the cliff) with some pelite, sandstone and volcanic material. The conglomerate is the predominant material in the cliff and presents a moderate cohesion The differentiated grain size distribution (from conglomerate to clay) is clearly demonstrating a not selective depositional environment, with high energy (flood plain). The siltstone exhibits an apparent moderate cohesion under dry conditions whereas, when saturated, the material tends to disaggregate completely. This is due, as demonstrated by mineralogical and petrographical analyses (Margottini, 2004), by the absence of cement in the matrix. All lithotypes forming the slope are variably jointed.

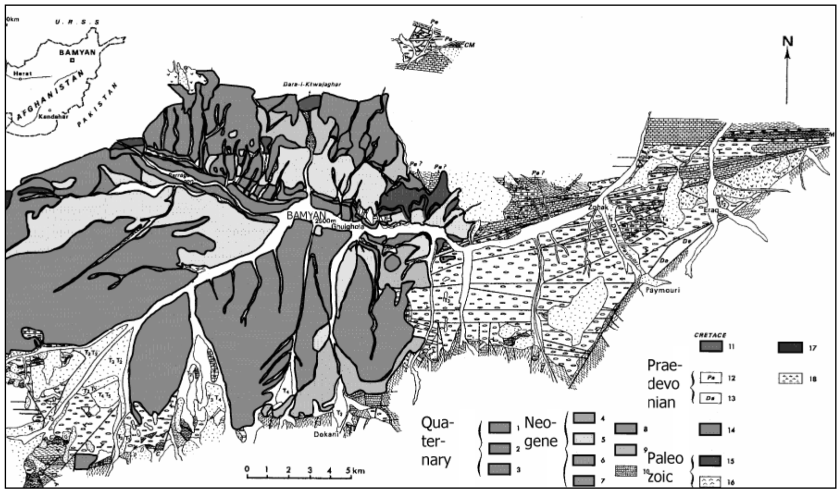

***Figure 1**: Geological map of Bamiyan (Lang, 1971; redrawn from Reineke, 2006)*

Geomorphological analysis

Bamiyan is located at 2,540m elevation on the N edge of the 600-km-long EW valley along the Herat fault, at the confluence of three different rivers. The flood valley is mainly formed by fluvial (alluvial and alluvial fans) and slope sediments (landslide and slope deposits). Its evolution is related with various factors such as lithological characteristics, tectonic activity, palaeoclimatic events, river and slope evolution in the cliff. The cliff where the Buddha statues are located presents a general E-W orientation an average slope inclination of ca. 85° and a total length of approx. 1,350m. The cliff can be divided into two distinct sectors: the western side, where the West Giant Buddha statue is located, shows a N65°E orientation with a length of approx. 820 m, whereas the eastern portion, where the East Giant Buddha is placed, exhibits a N95°E orientation and a length of ca. 525 m. The two segments are separated by a large alluvial cone generated by two distinct torrents flowing into the Bamiyan river, still very active, that have diverted the river flow towards SSE. The change of orientation from EW to NNE-SSW occurs in correspondence of the torrent located at E. This configuration is likely due to tectonic activity regarding the Herat fault system and local faults oriented NE-SW. The reconstruction of the geomorphological activity in the Bamiyan valley was developed with detailed field surveys integrated with a kinematic analysis on 18 distinct sectors of the cliff in order to define active and potential landslide types. In general terms, in the area the following active processes have been recognized:

- Water infiltration from the upper part of the cliff;
- Gully erosion in the upper catchment area and along the slope face;
- Accumulation of debris sediments at the toe; Mud flows;
- Toppling and rock-falls involving some isolated blocks;
- Rock-sliding along pre-existing joints;
- Active deformation processes with progressive opening of joints in the external part of the cliff.

***Figure 2** : Debris accumulation (left) and gully erosion on the slope face of the Bamiyan cliff*

Some processes, e.g. rock-falls and stress development along joints are affecting the niches of Buddha statues, accelerated also by the explosion of March 2001 that destroyed the statues. The Eastern Giant Buddha niche exhibits, at present, the most critical stability conditions. Recently, this area has been partly stabilized with urgent mitigation works. In the Western Giant Buddha site major effects were the collapse of the statue and the consequent instability of the back side of the niche.

Landslide deposits are diffusely outcropping along the slope toe, generated by rock falls and toppling of large conglomerate and siltstone blocks with modest run-out also evidenced by their typical sharp-edged shape. Block volumes vary from $<1m^3$ to $>10m^3$. Planar sliding deposits are diffusely outcropping at the base of the cliff and somewhat immersed and/or partially covered by the debris (Figure 2).

The top of the cliff, as well as the outer walls, are largely affected by diffuse and intense erosion of conglomerate and siltstone, especially in the western side of the cliff. This produces gully erosion that is the typical landform that outcrops in the slope face and in the upper parts of the Buddha cliff.

The concentration of gullies is very high in the very small basins located on the top of the cliff area, especially along the steep slopes of those tributaries creeks that form active debris cone when flowing into the Bamiyan valley.

The easily erodible soils with a weak structure like those forming the Bamiyan cliff, the absence of vegetation as well as climatic conditions of the area are prominent factors in accelerating this type of phenomenon in the catchments located on the back of the cliff, with a typical retrogressive activity.

Recent and past landslide activity and soil erosion are the consequence of climate fluctuations that occurred in Central Asia from Late Pleistocene up to present (Esper et al., 2002; Kamp et al., 2004; Bush, 2005).

Considering the main geomorphological features briefly described above and the long-term evolution of the cliff vs. climate and tectonic activity, three main stages have been recognized (Delmonaco & Margottini, 2007) and briefly described.

Stage 1: At the end of the last maximum glacial (13.5 ky BP) the rock slope experienced development of vertical cracks and deep rock sliding phenomena due to the deepening of the valley. This resulted in straining of rocks and development of parallel cracks and joints with E-W orientation. The intersection of this system with the one linked to the tectonic stress, oriented at S (dip direction) generated deep rock sliding phenomena affecting conglomerate and siltstone layers at the base of the cliff. Old landslides, mostly in inactive or quiescent state of activity, occurred before the human exploitation of the slope as demonstrated by stable caves excavated in the landslide body. Nevertheless the presence of two caves with evidence of displacement reveals the occurrence of rock slides at least after the 5-6th century AD.

Stage 2: The sea level rise after the cold peak terminated in the Early Holocene promoted large deposition of debris and alluvial sediments. The reduction of the potential energy in the slope and a consequent decrease of stress conditions concentrated at the slope toe changed landslide kinematics in the Bamiyan cliff from deep landslides to toppling-sliding failure mode that are affecting the middle-high sectors of the slope.

Stage 3: The so-called Little Ice Age (15th -19th centuries AD), with more humid conditions than present, have promoted an increase of erosion and debris production from the upper catchments especially in the western sector of the cliff. In the middle of the slope, where the two segments of the cliff with different orientations converge, the most active areas of debris production outcrops, evidenced by the coalescent debris cones that have diverted the flowing of the Bamiyan river through SSE. At present, arid climate conditions with low annual rainfall amount and concentrated precipitation promote deep erosion of loose sediments (e.g. gullies), mud flows along the channels and water infiltration inside the slope materials causing decrease of cohesion along the joints and acceleration of toppling/falling processes.

Landslide kinematic analysis

Structural setting analysis and potential instability failure modes of the slope-forming rocks has been undertaken in June 2007 in order to provide a preliminary sketch on potential morphological evolution of the cliff. The angle for most of the rock face is approximately 80°-88°. The outcropping soft rocks present prominent discontinuity sets whose origin, especially the joint system parallel to the slope face, can be associated to the geomorphological evolution of the valley as well as to tectonic setting (Ambraseys and Bilham, 2003). This situation has caused apparent slope instability phenom-

Table 1 *: List of structural stations with orientation and global localisation*

SITE ID	Dip Dir. (°)	Dip (°)	Location
Station 1	141	86	N34°49'44,1" E067°49'02.2"
Station 2	141	86	N34°49'47,3" E067°49'07.6"
Station 3	158	82	N34°49'47,4" E067°49'09.1"
Station 4	155	82	N34°49'47,5" E067°49'10.7"
Station 5	164	81	N34°49'47,7" E067°49'11.0"
Station 6	162	80	N34°49'49,1" E067°49'14.3"
Station 7	162	85	N34°49'51,0" E067°49'17.6"
Station 8	153	88	N34°49'51,4" E067°49'21.7"
Station 9	153	85	N34°49'51,8" E067°49'23.5"
Station 10	157	84	N34°49'54,8" E067°49'29.8"
Station 11	189	88	N34°49'54,5" E067°49'31.9"
Station 12	178	85	N34°49'54,1" E067°49'33.3"
Station 13	185	83	N34°49'53,3" E067°49'38.5"
Station 14	167	86	N34°49'52,9" E067°49'40.3"
Station 15	164	85	N34°49'53,3" E067°49'42.2"
Station 16	192	82	N34°49'53,2" E067°49'46.2"
Station 17	198	88	N34°49'52,9" E067°49'47.9"

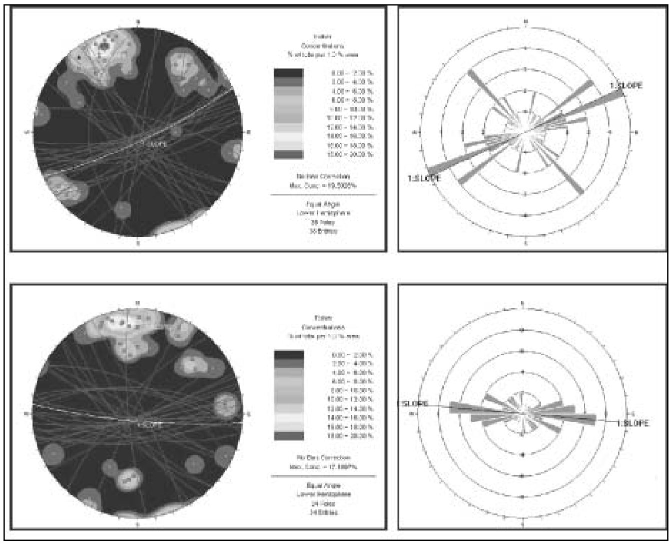

***Figure 3 and 4** : Joints orientation sets of the W part of Bamiyan cliff (stations 1-10, above) and of the E part of Bamiyan cliff (stations 11-17, below) represented through stereonet (left) and rose diagram (right)*

ena, somewhat aggravated by the explosions during the destruction of the Buddhist statues in 2001 around the niches areas. A total of 17 structural stations were selected by visual inspections in the areas of the cliff where historical structures (e.g. Buddha niches, external and underground caves) display prominent or potential instability conditions (Table 1).

The main joint orientation data in each observation point was represented with the Schmidt equal angle stereonet and rose diagrams. For the selected stations, kinematic analyses have been implemented to estimate the potential failure modes (toppling, plane and wedge sliding), that may develop along the slope. This was divided into two main sectors: W sector, where the Western Giant Buddha is located (stations 1-10) and the eastern side that includes the area of the Eastern Giant Buddha (stations 11-17). The two sectors displays different orientations, respectively 155/85° and 185/82°, due to tectonic effects (Figures 3 and 4).

The toppling analysis has provided the following results (Figure 5) considering a value of ’=30° along the joints in siltstone materials, as the weaker lithotypes where higher stress condition can develop.

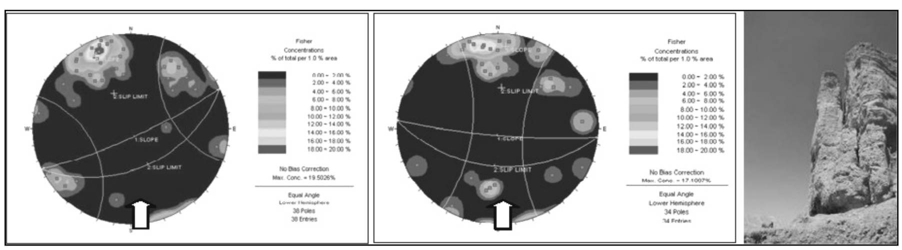

***Figure 5** : Results of kinematic analysis for toppling for W side (left) and E side of the cliff (middle); the arrows show the region where toppling is possible (between slip limit and lower stereonet border). Toppling evolution in the cliff (right)*

In general, the toppling potential seems to be higher in the W part of the cliff, especially in potential remobilized volumes. In the E side a potential toppling failure mode exhibits minor potential volumes involved due to a higher density of fractures in the jointed mass that presents, as well, a higher number of joint sets. The stereographic analysis for planar failure is shown in the Figure 6.

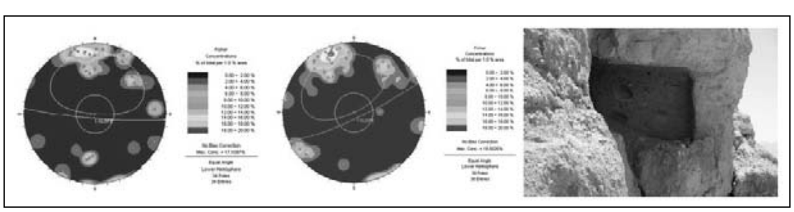

***Figure 6** : Results of kinematic analysis for planar sliding for W side (left) and E side of the cliff (middle); the arrows show the region where planar sliding is possible (inside the slip limit area and the upper friction cone line). Planar rock-slide involving an ancient cavity (right)*

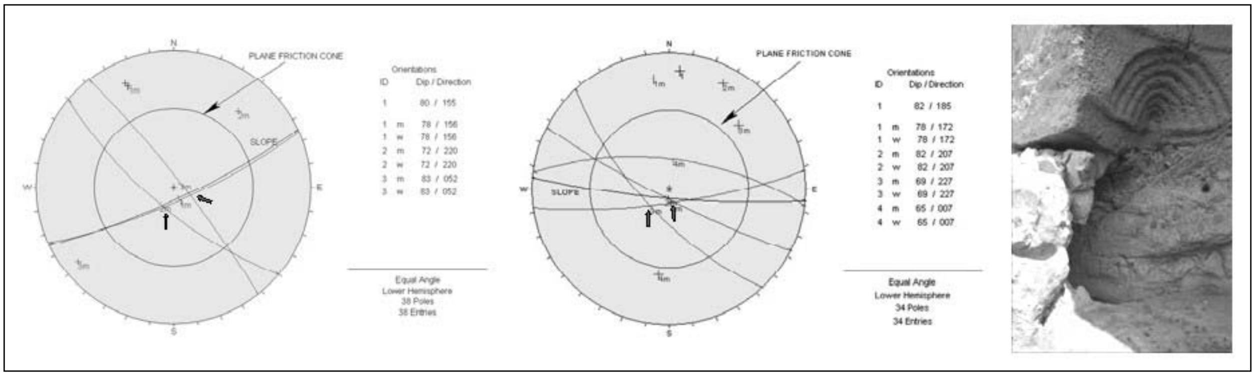

***Figure 7** : Results of kinematic analysis for wedge failure for W side (left) and E side of the cliff (middle); the arrows show the intersections of planes that may cause sliding inside the potential area (crescent shaped region between slope limit and lower friction cone). Potential wedge sliding along the cliff (right).*

Planar sliding is highly potential in both sides of the cliff, also as a secondary movement connected with toppling failure, that, factually, determines the sliding of vertical blocks previously deformed following a typical toppling evolution. This occurs especially when the "pivot" of the block is located inside a siltstone layer where the major stress is concentrated. In that case the evolution of failure is that typical of a sliding, sometimes with the development of circular-shaped rupture surface in cohesive materials (Mohr-Coulomb behavior of weak siltstone). Kinematic analysis for wedge failure is shown in Figure 7.

Major planes have been selected with the Terzaghi weighted mean statistical technique. In the W side, wedge failure is possible in rock blocks delimitated by joints 1-2 (oriented respectively158°/76° and 220°/72°) and 1-3 (158°/76° and 052°/83°). In the E side wedge failure can be promoted by joints 1-2 (172°/78° and 207°/82° oriented) and joints 1-3 (172°/78° and 227°/69°). It can be affirmed that in the W portion, since the most important system is the discontinuity oriented parallel to the slope, this kind of failure mode is very difficult to occur, since this system primarily produces rock falls and toppling phenomena. As a matter of fact, no special evidence of wedge potential, although theoretically possible, has been surveyed in this area. On the contrary, the E side has shown wide sectors of the slope where wedge failure has been detected, especially in the lower parts of the slope where siltstone is prevalent, although this kind of failure mode can mobilize small volume of rocks due high frequency of discontinuities. According to the main geomorphic processes reconstructed in the Bamiyan cliff, a geomorphological map has been produced (Figure 8).

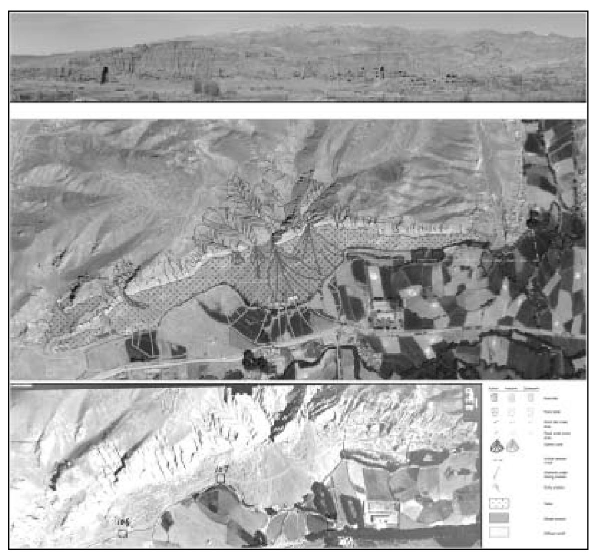

***Figure 8** : View of the Bamiyan valley (upper) and geomorphological map of the cliff where the giant statues of Buddha are located. The distance between the niches is 790m. The lower aerial photo is the first image of the Bamiyan valley (late '60)*

The geomorphological investigation carried out in Bamiyan on the cliff where the giant statues of Buddha are located has evidenced that several active processes are affecting the area. Intense erosion is mainly affecting the upper part of the cliff and the slope face whereas landslide processes are involving different sectors of the slope. According to kinematic analysis undertaken in the structural stations detected along the cliff of Bamiyan, the slope may experienced, as in the past, toppling, planar sliding and wedge failure, although with distinct perspectives.

Planar sliding is the most diffuse failure potential both sides of the cliff, although most of the movements have occurred in the past. This failure type can be considered as the secondary movement type after toppling evolution of unstable blocks, especially when the failure surface is located inside siltstone layers. Toppling of rock blocks is equally diffuse and may be considered the most hazardous landslide type for all the cliff, even if in the W side it can be expected a higher magnitude of events with respect to the E part of the cliff. Wedge sliding is potentially developing in both parts of the cliff. Nevertheless, the structural conditions suggest that this type of movement is more probable in the eastern sector, characterised by high potential frequency and low magnitude of events, as also surveyed during the field mission of June 2007.

Acknowledgments

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Landslide Vulnerability of Bangladesh Hills and Sustainable Management Options: A Case Study of 2007 Landslide in Chittagong City

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Abstract
Bangladesh hills are basically composed of unconsolidated sedimentary rocks such as sandstone, siltstone, shale and conglomerate. Unsustainable landsuse and alteration in the hills including indiscriminate deforestation and hill cutting are two major factors in Bangladesh that aggravated the landslide vulnerability in the hilly areas. Excessive rainfall within shorter time span often cause landslide specifically in the areas composed of unconsolidated rocks. This situation is further aggravated if the slopes are steep and exposed because of indiscriminate hill cutting. Because of climate change, the country is experiencing extremely high intensity rainfall in the recent years which is making the situation real grave. Chittagong city is the second largest city of Bangladesh comprising hills formed during tertiary time. A north-south hill range crosses the city and many settlements and slums have been developed in the foothills and lower income people are living in these areas in a risky situation. On 11 June, 2007, a massive landslide happened in Chittagong city area. As a result, a number of foothill settlements and slums were demolished; more than 90 people died and huge resource destruction took place. Landslide is a common event in Chittaogng and Chittagong Hill Tract region of Bangladesh but intensity and magnitude of the recent occurrence has crossed all previous events. This study mainly investigate the causes and damage level and also identify vulnerable areas of Chittaogng city in terms of the risk of landslide. Potential sustainable management provisions have also been explored in this study.

General Background

Physiographically, most of the area of Bangladesh is floodplain and only 18% is hilly and tract area (Islam & Uddin, 2001). According to geological time scale, hilly area of Bangladesh developed in tertiary age. The bedrock and soil structure of these hills are not stable, for which reason these areas are highly prone to landslide. Bangladesh is a multi-hazard prone country and landslide is not new phenomenon in Bangladesh. However, it was never been hazardous like the recent incident of Chittagong. On 11 June 2007, the city dwellers of Chittagong have experienced a terrible landslide. As a result, at least 91 peoples died and huge destruction of resources took place. Chittagong hills are degrading by different anthropogenic stress such as, hill cutting for construction, sand and clay mining purpose, increasing settlement in foothills, deforestation etc. These factors are causing the landslide and landslide vulnerability is increasing day-by-day. This landslide should be considered as cautionary signal and it is essential to think about sustainable land management in Chittagong city to reduce the risk of future loss of both human lives and resources.

Aim & Objectives of this Study

The aim of this study is to assess the landslide vulnerability and recommend sustainable land management provisions for reducing the risk of landslide in Chittagong city. To fulfill this aim, the specific objectives of the study are to;

- Identify the landslide prone areas;
- Identify the general and specific causes of landslide in Chittagong city with special reference to June 2007 landslide; and
- Explore the sustainable land management strategies for reducing the risk of landslide.

Data and Methods

In addition to field survey and primary data collection, both published and unpublished data have been utilized in this study (Figure 1). Several focus group discussions (FGDs) have been conducted in hilly areas of Chittagong city for identifying the vulnerable zones. A GPS (Global Positioning System) survey was conducted for preparing the landslide prone zoning map.

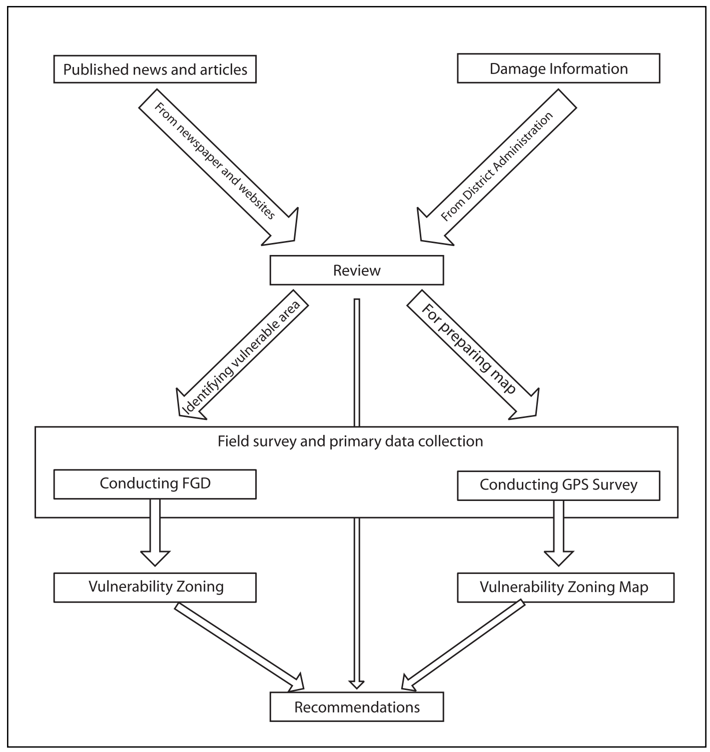

***Figure 1:** Methodology flow chart*

Physiography of Bangladesh Hills, Landuse and Vulnerabilities

About 82% land of Bangladesh can be identified as recent plains and 18% as terrace and hilly area. Pleistocene terrace has covered 10% and eastern and north-eastern tertiary hill are of only 8% of the country (Islam & Uddin, 2001). Physiographically, hilly Regions can be divided into the following three sub-regions;

i) Chittagong and Chittagong Hill Tract
ii) Hill Ranges of Northeastern Sylhet
iii) Hill along the narrow northern strip of Sylhet and Mymensingh

The following map (Figure 2) shows the physiography of Bangladesh. Hills of Bangladesh have been uplifted and folded into a series of pitching anticlines and synclines. The higher hill ranges in the Chittagong Hill Tracts, Chittagong and Sylhet regions regarded as late Oligocene to mid-Miocence in age. Lower hills are mainly underlain by little-consolidated sands and shales of the Dupi Tila formation, which may be from late-Miocence age. (Brammer, 1996). These hills are mainly composed by unconsolidated or little-consolidated beds of sandstones, siltstones and shales, together with minor beds of limestone and conglomerates. Nature of parent materials strongly determines the texture of the soils. Shale results heavy silt loam or silty clay loam subsoil. Soils developed on sandstone have dominant textural class of sandy loams with occasional loamy sand or loam texture. Soils subject to erosion have topsoil with less clay content. The steepness of the landscape determines the depth of the soil. Soils are in general shallow in depth. Soils developed at steep or very steep slopes of the hilly regions are susceptible to erosion (including landslips on some soils). Washout materials are deposited at the foot of the hills (FAO, 1988).

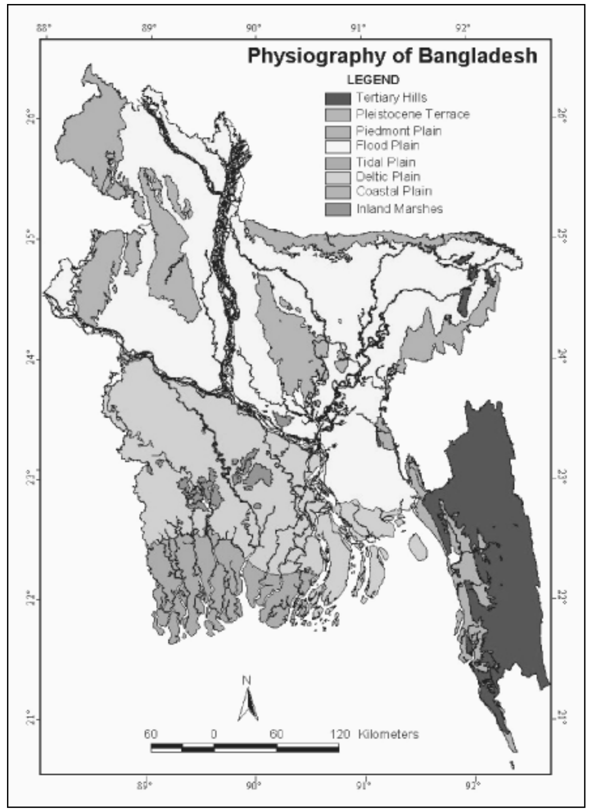

Figure 2: *Map showing Generalized Physiography of Bangaldesh.*

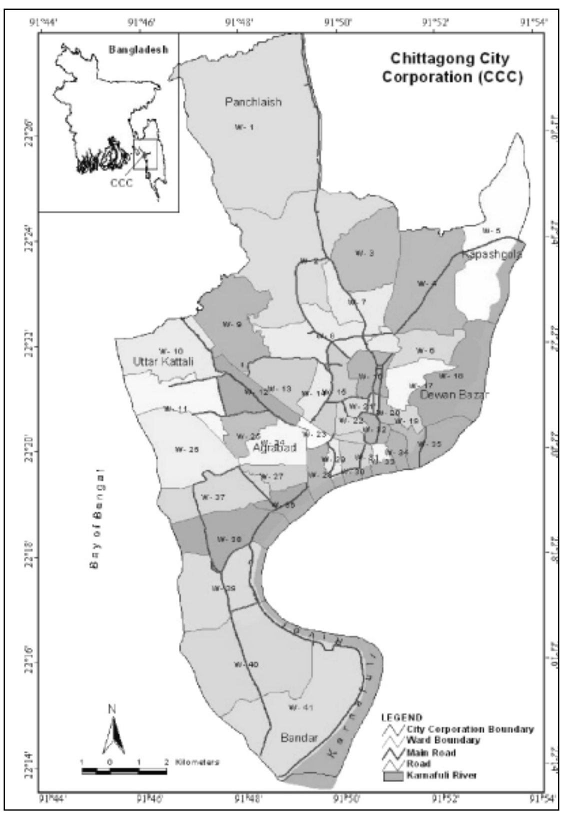

Figure 3: *Map of Chittagong City.*

Location and Physical Characteristics of Chittagong City

Chittagong is the second largest city of Bangladesh. The city lies 21°54' North to 22° 59' north latitude and 91° 17' east to 92° 14' east longitude and extend north bank of the Karnafuli River to west bank of the Halda River. Both in terms of economy and ecology, this is a very important city. Country's largest and main seaport is situated here, which play a great role in country's economic development.

A north-south central hill range extends into the urban zone from the north and gradually loses height as it comes closer to the river. The city comprises area of small hills and narrow valleys, bounded by the Karnaphuli to the south, the coastal plain and the Bay of Bengal to the west and the floodplain of the Halda to the East (Figure 3). The highest ground level within the city area is about 60m above MSL.

Landslide Tend in Chittagong Region

Due to weak structure and indiscriminate use of hills, landslide occurred frequently in Chittagong hilly region. Table 1 below shows major landslide occurence in Chittagong region.

***Table 1**: Major landslide occurrence in Chittagong region.*

Date	Landslide Area
1968	Kaptai – Chandraghona Road
1970	Ghagra – Rangamati Road
May 30, 1990	Jhagar beel area, Rangamati
July, 1997	Charaipada, Bandarban
August 11 & 13, 1999	Bandarban & Chittagong
June, 2000	Chittagong University Campus & Chittagong City
June, 2007	Chittagong City and Chittagong University Campus

Source: Banglapedia

Causes of the Landslide

In a landslide or rock falls, movements of the materials depend on the slope. In most cases, material movement happens because of the slope instability. Several geological, morphological, and human induced changes cause these slope instabilities. Chittagong hills are the part of tertiary hills. The geological structure and soils are weak and also have steep slopes which increase the risk vulnerable by landslide. The main causes that triggered slope instability induced landslides in Chittagong region of Bangladesh could be summarized as follows:

Hill cutting

Presently indiscriminate hill cutting is one of the major causes of landslide in Chittagong city (Figure 4). Hills of Chittagong is being cut for building construction, develop residential/housing area, clay and sand mining and developing road network. The Chittagong city is a densely populated area. For accommodation people build house on the top of the hills or on slope or on the foot of hills without following the existing rules and regulations. Greedy influential people and muscle-men invade the Government hills and build temporary houses on them to earn money by renting them to the poor people. Poor people who live in those houses are highly vulnerable to landslide. Because of hill cutting, the slopes become instable. The hills of Chittagong were cut with slopes of 70-80 degrees.

When it rains, water dissolves the minerals of the soil of the hills that loosen its compaction. Soils of the hills also become heavy by absorbing rainwater. If rain intensity is too high, minerals of soil dissolve very quickly and the soil turns into mud and becomes very heavy. The steep slope of the hill cannot bear the mass weight of the wet soil or mud that results the landslide. The recent landslide in Chittagong city was the result of hill cutting and steep slopes of the hills. The most affected areas because

Figure 4: Showing the landslide happened due to hill cutting for construction purpose

of indiscriminate hill cutting are Khulshi, Panchlaish, Sholoshahar, Baizid Bostami, Foy's Lake, Lalkhan Bazar, Pahartali, Kattali and Polytechnic area.

Deforestation

Deforestation in the hill areas is another major reason of landslide in Chittagong. Deforested areas are more prone to landslide than a forested area. Vegetation protects the soils and makes slope stable which reduce the risk of landslides. Large trees provide strong root structures into the earth that anchor the soil and protect it from any erosion. Khulshi, Batali hill and hills near Foy's lake are massively affected by deforestation in Chittagong city.

Rainfall

The average yearly rainfall of Chittagong is approximately 3000 mm. The highest rainfall happens in the month of June (Figure 5). Landslide frequency in Bangladesh is the highest in the month of June as well. Figure 5 shows strong relationships between landslide and rainfall volume. More rainfall increases

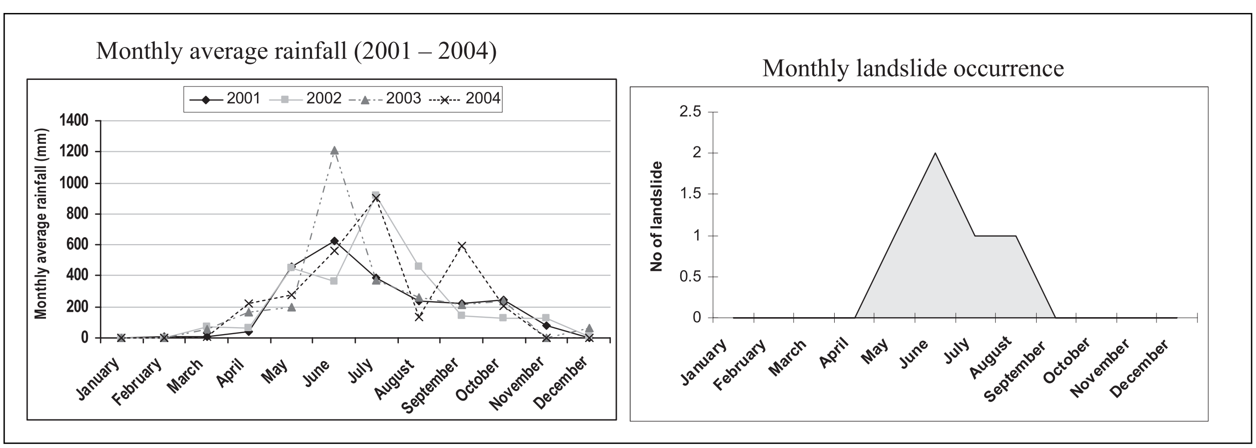

Figure 5: Relationship between rainfall and landslide occurrence in Bangladesh hills (Source: BBS, 2007)

the probability of landslide. Rainfall causes landslide by loosening the soil compaction and also by increasing the weight of the soils of the hills. The hills of Chittagong mainly comprise sandstones, shales and siltstones which have been partially consolidated to varying degrees, and which locally contain lime or pyrites. Seepage down of the rainwater dissolves these limestone and soils of the slopes are converted into clay that moves downward causing landslide. The rainfall rate of Chittagong is much higher than most parts of the country. Sometimes, intensive and massive rainfall occurs due to depression or cyclone in the Bay of Bengal. The last landslide occurred during this type of massive rainfall in Chittagong city.

Earthquake

Although earthquake was not a reason for the recent landslide in Chittagong, earthquake may cause high intensity landslides in Chittagong.

8. Affected Area and Damage Level

The landslide on June 11, 2007 occurred in several areas of Chittagong. Damage level and magnitude of the landslide surpassed all previous occurrences in Bangladesh. Ma jor affected areas of the landslide are the foothill settlements, slum of Lebubagan (Chittagong Cantonment), Baizid Bostami, Kusumbag, and Lalkhan baza ar hilly area. Damage level of these landslides are shown below in Tables 2 & 3:

Table – 2*: Number of Death as a Result of the Landslide of 11 June 2007*

Area	**Thana**	**No. of Death**			
		Female	Male	Children	Total
Lebubagan (ChittagongCantonment)	Hathazari	17	14	41	72
Baizid Bostami	Baizid	3	1	1	5
Kushumbag Lalkhanbazar	Khulshi	6	2	6	14
Total number of death					**91**

Source*: Report of 6 August, 2007, District Administration, Chittagong*

Table – 3*: Number of affected families by landslide of 11 June 2007*

Area	**Thana**	**No. of Affected Family**		
		Severe Affected	Partial Affected	Total
Lebubagan (Chittagong Cantonment)	Hathazari	235	173	1554
Baizid Bostami	Baizid	1	320	321
Kushumbag Lalkhanbazar	Khulshi	87	110	197
Total Affected Family				**2072**

Source*: Report of 6 August, 2007, District Administration, Chittagong*

Landslide Vulnerability in Chittagong

Although tertiary hills of Chittagong are prone to landslides due to its formation and structure but it can be reduced by stopping hill cutting and deforestation etc. Risk is higher where settlement exists on the foothills and poor people live within the areas. Figure 6 shows the generalized landuse and landslide prone areas of Chittagong city.

High Risk Areas

Lebubagan Area: Lebubagan area is located near Chittagong Cantonment in Hathazari Thana. Maximum inhabitants of Lebubagan are poor labor/workers and live in foothill slum. They migrated from plain land and coastal area because of poverty and riverbank erosion. They do not have enough knowledge about the risk of landslide and how it can create a risky situation for them.

Baizid Bostami Area: The hills under Armed Police Battalion - 2 (APBN-2) in Baizid Bostami thana of Chittagong city. This is a lower income group residential area and most of the inhabitants live in foothill areas. Few people live on the hill top. These are Government owned land under APBN – 2. People of this area sell their labor in the industries built and located within the foothill areas. After the landslide, the APBN resettled only a few families to safer places. It has been observed that most people did not move from these risky locations. Some of the industries are still there under high vulnerability and people are still working in these industries.

Kushumbag Residential Area: Kushumbag residential area is located near the Chittagong Metropolitan Police line. This is a middle class residential area. Lots of houses and shops are built at the foothill though landslides are common in this area.

Batali Hill Area: This area is highly vulnerable as the hill is surrounded by foothill slums and settlements. Most of the inhabitants are poor factory workers. Any large scale landslide can cause massive destruction to slums and cause death of many people.

Motijharna Area : Motijharna is located at Lalkhanbazar area near Tigerpass. This area is also heavily populated and occupied by lower income groups.

Moderate Risk Area

Foy's Lake Area: A few housing areas are being developed behind the hills of Foy's lake. A massive hill cutting process is in progress. However, this area is not very populous and in some places, houses are yet to be built.

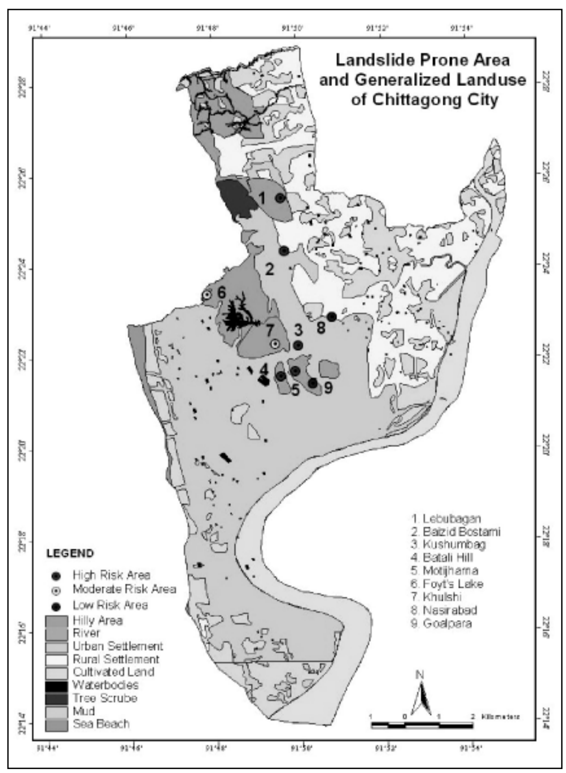

Figure 6 *: Landslide vulnerability and generalized landuse of Chittagong City.*

Khulshi Area: This is a posh residential area located in the north and south of Khulshi hill. Indiscriminate hill cutting is common in this area. Most people who constructed houses in this area are rich and built protection wall (retaining wall) to protect their houses from landslide.

Low Vulnerable Areas

Nasirabad Area: Nasirabad Residential area is a posh residential area in Chittagong City. Most of the constructions are completed. There are few hills surrounding this area. Inhabitants of Nasirabad protected their houses by constructing concrete wall (retaining wall). For this reason, vulnerability of this area is less than other hilly areas of Chittagong city.

Goalpara Slum: Goalpara slum is located near the Tigerpass and Chittagong Stadium. This area is populated by poor slum dwellers in the foothill. However, the hills are not too high and therefore the risk is low in this area.

Sustainable Management Options

As mentioned earlier, vulnerability of landslide depends on location, landuse, land cover, rainfall as well as weather, geological structure and type of human a ctivities. Because of all these external and internal phenomena, it is not possible to prevent the landslide of Chittagong completely. However, it is possible to reduce the risk and landslide intensity as well as frequency by adopting the following management options.

Landslide vulnerability assessment and zoning

Landslide vulnerability assessment and zoning is a prerequisite for sustainable management. At present, there is no landslide vulnerability zoning map for Chittagong city. The hills of Chittagong are composed of different characteristics such as few hills contain foothill settlements (high class, middle class and slum), few are with vegetation, few are completely barren, few contains both hill top and foothill settlement. Because of this landslide vulnerability varies depending on different types of landuse. On the basis of geomorphologic biological and socio-economic analysis the zoning should be administered.

Strict compliance of zoning and other legal and policy instruments

City planning, landuse and utilization must adhere to the recommended land zoning and relevant policy and legal provisions.

Re-location of the foothill slums

Several large slums are located in different foothills of Chittagong. Most of these are on Government-owned lands grabbed by the influential people. These slums are much cheaper to rent than other areas and therefore, populated by very poor people. The slums are very densely populated and made of bamboo and earthen materials which extremely exposed to the risk of landslide. This risk can be reduced by relocating these slums to safer places.

Proper compliance of existing legal provisions

Hill cutting is one of the main causes of landslides hazard in Chittagong city area. Landslide related hazards can be reduced or even probability of landsliding can be reduced if only hill cutting could have been prohibited. In cases of the places, where hill cutting has already taken place, sustainable structural measures such as retaining wall can be explored as mitigation options.

Real time monitoring and early warning

Most of the landslides in Chittagong city and Chittagong hilly areas happen during the rainy season when rainfall intensity is very high. Therefore rainy seasons need to be monitored closely to assess the situation, especially in the landslide prone areas. In case of any potential landslide, people of the concerned localities need to be informed through early warning system.

Enhancement of Public awareness

Comprehensive awareness is to be administered to enhance public awareness about the harmful effects of hill cutting and associated legal restrictions. Awareness program should also contain the significance of proper landuse as well as sustainable land management.

Establishment of the emergency response and recovery team and facilities

There is no special team for emergency rescue and recovery in response to potential landslide disaster in Chittagong city. A special professional team should be formed and the fire brigade and police department should be trained up on the emergency rescue and recovery aspects. In addition, community based rescue teams should also be developed from the vulnerable communities to help the professional rescue team.

Addressing poverty issue

If it is critically observed, a correlation will be found between the "landslide victims" and the "poverty". As mentioned earlier, the poor people are living in the landslide-prone areas who can not afford a safer place to stay. Therefore, addressing poverty issue should be considered as a priority to deal with the issue.

10.9 Harmonization of institutional mandates

The land and landslide management of the Chittagong city is found to be a complex one. Hills are treated as khas lands (Government-owned land) and district administration is authorized to control the leasing activities. On the other hand, the Chittagong Development Authority (CDA) is authorized to develop urban development plan and Chittagong City Corporation (CCC) is authorized to implement different development plans. Few hills are owned by Bangladesh Railway and Bangladesh Army and being managed under different management strategy. There is no single authority for managing the land in Chittagong city. Moreover, it is not possible to manage land through a single authority because different organization plays different roles for land management. It is essential to develop an inter-organizational coordination mechanism to working together for sustainable land management as well as to carry out activities related to emergency response. Figure 7 below shows the proposed relationship between different organizations for sustainable land management in Chittagong city:

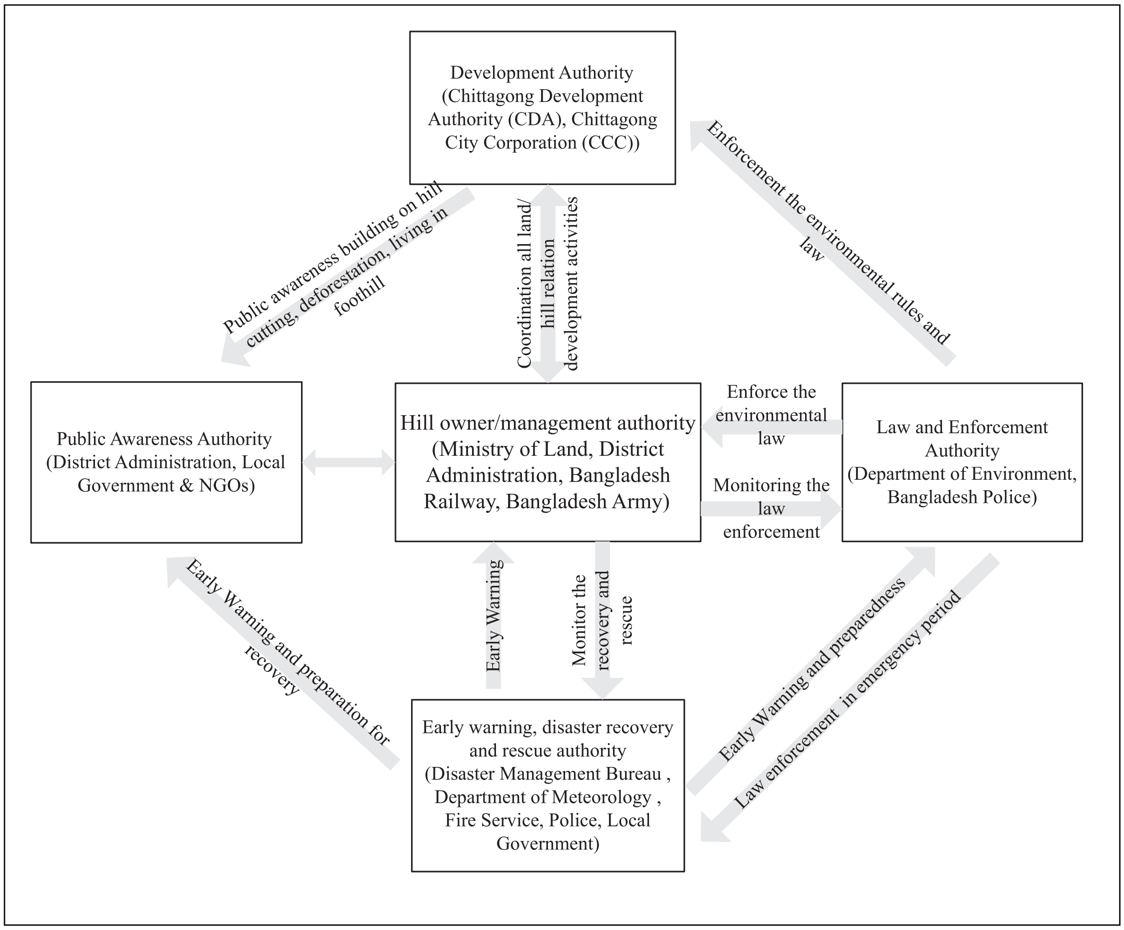

Figure 7: *Proposed harmonized relationship between different organizations of Chittagong for sustainable land and landuse management in Chittagong.*

Review of the existing legal and policy provisions and its compliance status

A thorough analysis of the existing laws and policies relevant to land management is required to update and harmonize polices, plans and legal instruments. In general, similar to many other sectors, proper compliance of the land related legal and policy provisions are not at the required level. For instance, on March 9, 2002 the Department of Environment (DoE) notified a public notice against illegal hill cutting but unfortunately the hill cutting activities did not stop due to lack of enforcement of this notice. Subsequently, DoE again circulated a notification on July 10, 2007, banning all types hill cutting under the Bangladesh Environmental Conservation Act (Law No. 1, 1995, rule 4(1)). If this notification is not properly monitored by concerned authorities, the hill cutting activities will not stop in the city.

Conclusion

In a nutshell, to enhance the city governance, policy and institutional aspects are to be reviewed considering the issues mentioned above. Appropriate facilitating roles of the concerned Government agencies can create an enabling situation for an effective public-private-community partnership towards achieving sustainable cities in Bangladesh.

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Landslides in Bhutan

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Abstract
Landslide poses real danger in the Himalayan Kingdom of Bhutan. Mountainous terrain forces construction of roads and other infrastructure up on the steep slopes that are mainly thrusted and folded and consequently fractured and weathered. This paper presents the overall view of the landslide problems, mitigation methods and the need to further the risk management plan. It also provides a glimpse of the social, economical and political situation of the Kingdom among others.

Introduction

Bhutan is a small kingdom covering an area of 46,500 square kilometers in the eastern part of the Himalayan Range between latitudes 26° 40′ and 28°20′ north and longitude 88°45′ and 92°7′ east (Figure 1). It is surrounded by the Tibetan Plateau in the north, the Bengal and Assam Plains in the south, Arunachal Pradesh in the east and the Darjeeling and the Sikkim Himalaya in the west.

Bhutan is mountainous with elevations ranging from 150 m up to 8,000 m. Three main ethnic groups live in Bhutan. Ngalops live in the north-western region. Sharchops inhabit eastern and central region and Lhotshampas in the southern foothill districts. The economy, one of the world's smallest, is based on agriculture and forestry. About 70% of the population depends on agriculture for their livelihood. Agriculture consists mainly of subsistence farming and animal husbandry. Agriculture share to GDP is 36.4% in 2000. Bhutan's hydropower and tourism are key financial resources. The hydroelectricity power sector is the single biggest revenue earner of the Kingdom with hydro-electricity power potential of about 30,000 MW. Most of the rivers come from the glaciers and altitude difference provides huge potential for hydropower.

***Figure 1**: Map of Bhutan.*

Rugged terrain makes building of roads and other infrastructure difficult and expensive. Each economic program takes into account the people's desire to protect the country's environment and cultural traditions. Bhutan's economic growth climbed to 7.7% in 2002 from 6.6% the previous year.

Bhutan is ruled by a constitutional monarch. His Majesty King Jigme Singye Wangchuck governs with the support of National Assembly and Council of Ministers. Since June 30, 2003, there are ten full fledged Ministers. Ministers are elected for a period of five years term. The prime ministerial post is rotated among the cabinet ministers on annual basis.

The National Assembly of Bhutan has 150 members of which 105 members (chimes) are elected by the heads of the households. Important decisions and laws are made during this Assembly.

The Kingdom is divided into 20 districts. The Dzongda or the District Governor is the head of the Government in the district. He is responsible for implementation of the Government policies, development projects besides maintaining law and order.

Bhutan is one of the least populated countries in South Asia. The population of Bhutan was estimated at 716, 423 and population growth was 2.4% in 2002.

Bhutan has a wide variety of climate conditions influenced by topography, elevation and rainfall patterns. In general, precipitation diminishes significantly from south to north. The winters are dry and rainfall is heavy during May - September. The climate is tropical in southern plains, cool winters and hot summers in central valleys, and severe winters and cool summers in northern Bhutan Himalayas.

Land use is influenced by the diversity of climate and topography related to altitude. More than 70% of the total land is under forest as per the central Government policy. Major landforms consist of mountains and valleys. Agriculture is mainly practiced in the valleys and mountains are generally forested. Only less than 8% of the total land is fit for agriculture.

The regional geological setting of the Bhutan Himalaya has been described by Gansser (1983). Much of Bhutan is dominated by Higher Himalayan Crystalline Complex (HHC) which outcrops over a north-south width of about 60-100 km between South Tibetan Detachment (STD) along the northern border of Bhutan and the Main Central Thrust (MCT). To the south of the MCT is the Lesser Himalaya. The MCT dips to the north and separates the high grade gneiss of the HHC in the hanging wall, from the greenschist metamorphic rocks of the Lesser Himalaya. So an inverted metamorphic gradient is associated with this thrust. In general, the tectonic setting of Bhutan Himalayas shares similarities with Himalayas of Nepal and India. Major tectono-stratigraphic units and structures are Siwalik Group, the Main Boundary Thrust (MBT), the Lesser Himalayan Sequence (LHS), the Main Central Thrust (MCT), the Higher Himalayan Crystalline Complex (HHC), and the South Tibetan Detachment (STD).

Bhutan is a developing country. The problems of landslides are an important consideration in infrastructure planning and other developmental activities.

Extent of the landslide problem

With the development activities taking place in the Himalayan regions a new focus has been shifted to the landslide problems. The geologic fragility of the Himalayan area has been highlighted and there has been an over emphasis on the macro scale in literature and very little on the micro scale. Due to the tectonics that have resulted the Himalayas, and Bhutan being part of that region, it has always been recognized as an area prone to natural hazards including the landslides.

The entire northern part of Bhutan is covered by ice and snow, resulting in glaciers that are the sources of the rivers that traverse from north to the south. There are 667 glaciers and 2674 glacial lakes in Bhutan alone. Although these glaciers are perennial sources of water they are also potential for flood disasters. In total, 24 glacial lakes have been identified as potentially dangerous.

The criteria for identifying potentially dangerous glacial lakes are based on field observations, processes and records of past events, geomorphological and geotechnical characteristics of the lake and surroundings, and other physical conditions. Besides, the conditions of lakes, dams, associated mother glaciers, and topographic features around the lakes and glaciers are also studied for the hazard assessment of the glacial lakes.

***Figure 2**: Luggye glacial lake.*

Change in climate is resulting in melting of these glaciers. Consequently, the volume of the glacial lakes increases, thereby increasing the hydrostatic pressure on barrier dams (created by glacial debris), which give way causing catastrophic outburst. For instance, in 1994, Luggye glacial lake (Figure 2) outburst in Lunana flooded and damaged rice fields, bridges, houses and the dzongs (Figure 3), demonstrating Bhutan's vulnerability to such extreme events. GLOF and flash floods had also occurred in the same region earlier in 1950, 1960 and 1968.

***Figure 3:** Punakha Dzong (partly destroyed by GLOF.*

If the land in the north is highly prone to glaciers and related natural hazards then the area in the east and south are subjects to several landslides, especially in the rainy monsoon months. A lateral road runs from the west to east across Bhutan. Due to extreme Alpine terrain and deep valleys, landslides often block the way to the east.

Recently, on August 16, 2004 a flash flood struck eastern Bhutan (Tashigang, Mongar and Lhuentse). This flood and the consequent landslides claimed 11 lives. A total of 29 houses were washed away, about 26 collapsed and 107 were partially damaged. According to the Kuensel, the national newspaper 22 bridges had been damaged and 39 irrigation channels were either damaged or washed away. About 160 acres of wet land and 500 acres of dry land were damaged.

The landslides triggered by road cutting are quite common in Bhutan. During the rainy months of May-September, landslides crop up at various places blocking the roads. The life line of Bhutan, the road from Phuntsholing to Thimphu often gets blocked by landslide debris. This is the road that brings in the consumer goods from India. When this road gets blocked, the capital city, Thimphu gets cut of from India, the single most important partner of trade for Bhutan. Sorchen landslide (Figure 4) is a very popular slide for which a risk treatment has not been found for several years. This is a deep seated slide in rocks of moderate to highly weathered phyllites. Just two years ago, the Government has decided to totally do away with this landslide and built an alternative route as an avoidance strategy.

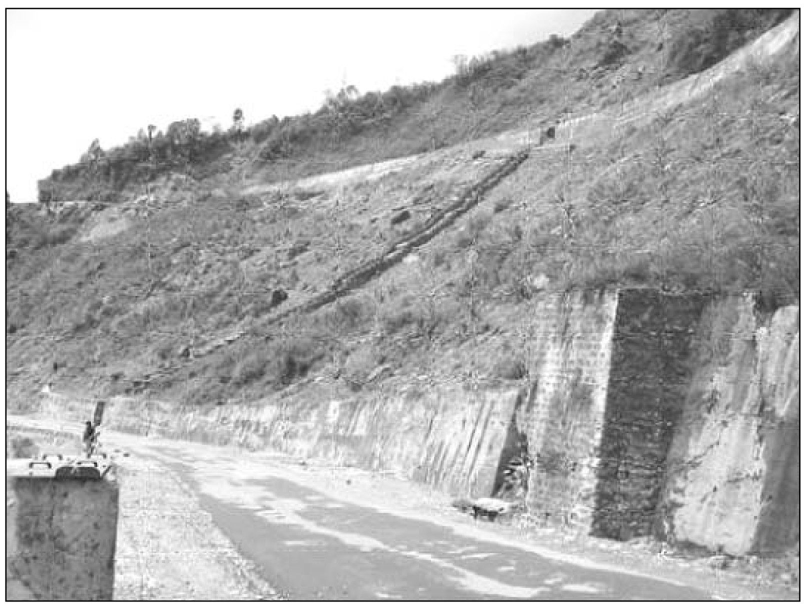

***Figure 4:** Sorchen landslide.*

Landslide-dams occur in the steep, narrow valleys of the high rugged mountains of Bhutan as these valleys only require relatively small amounts of material to form blockages. This is extremely dangerous for Bhutan because the country relies heavily on its hydro- electricity powers, which are built on these rivers. For example, on the morning of September 10, 2003 a huge combination of rock and earth slump occurred in Tsatichhu River blocking it and forming a dam (Figure 5). A lake started to form immediately behind the dam. The height of this landslide dam was 140 m over the original river bottom. The discharge into this lake was estimated to be 0.5 m^3/sec in dry season and 5 m^3/sec in monsoons. Bursting of this lake could damage Kurichu Hydro Power project, one of the most important undertakings of the Kingdom. Therefore, landslides have a huge adverse impact on development activities of the country.

Causative factors

In the Himalayan region of which Bhutan is a part of, the landslides are scale-dependent, ranging from the magnitude of mountain ranges, through lateral spreading, to the smallest slope failures. The morphology of the slopes consequent to slope failures are complex and controlled by many factors, such as lithology, rock-mass strength and other physical properties.

***Figure 5**: Tsatichu landslide dam.*

Based on the field study carried out on a micro scale in the Himalayas, the causes of the landslides are due to both natural geological activities as well as possible human related causes. The natural causes include tectonic activities that have formed the region into high relief thrusted and folded mountains. Unpredictable precipitation levels during summer monsoon months and the steepness of the slopes, undercutting of the banks by deeply incised rivers are some of the causes of landslides. Although so far the disasters from the earthquake have been rare, Bhutan should prepare for earthquake as it lies in a seismically active zone (4-5 on Richter scale).

In the Bhutan Himalaya, landslides are often triggered by toe cutting of the slope for road construction. Intensive deforestation for agriculture leaves the land vulnerable to landslides. The possible human impact could well be the result of construction of road and other infrastructure on these slopes without proper planning. Blasting is also one of the main triggers for landslides. With the growth of population and subsequent pressure on natural resources, the landslide problem can only be expected to escalate.

]Rainfall induced slope failure is the most common geo-environment hazard in Bhutan. Saturation of soil not also increases the pore water pressure but also degrades soil strength parameters. There is a direct correlation between the amount of rainfall and the incidence of landslides. The areas that are most prone to rainfall induced failures are heavily fractured and weathered rocks of phyllites, slates and schists that contain high amounts of clay minerals. The southern part of Bhutan which forms part of Lesser Himalayas is such an area. The risk from such slope failure will only increase as more roads are cut into the hills and mountains.

Unpredictable monsoon rainfall is also one main cause of flash floods in the southern parts of Bhutan. In 2000, a flash flood washed away major parts of Phuntsholing (the second biggest town after the capital city, Thimphu) destroying several houses, bridges and lives.

Hazard Zonation

The Department of Geology and Mines has been involved in preparing hazard maps by applying risk principles. This involves preparation of maps summarizing observations on geology, geomorphology, and in particular the distribution of landslide processes including use of local records, interpretations of aerial photographs and field observations. But this has been done only along some of the existing highways and important sites of new towns and projects due to manpower and other resources constraints.

During the month of January 2004, a geo-hazard map has been prepared for the road connecting Phuntsholing, (a border town) with Tala, a site for Bhutan's largest hydro-power project. This stretch was chosen for zoning because the area is geologically weak marked my several shear zones as well as weathered and folded phyllite rocks turning into clay. A geo-hazard map was also prepared for the highway connecting Sarbang with Chirang. This is a 62 km stretch in the southern part of the country, where the geology is most prone to landslides. Similarly, the Department is in the process of preparing hazard zonations maps for the other critical highways and new towns.

Often the hazard information is plotted on 1:50,000 scale contour maps since they are readily available. However, such maps are inadequate for detailed study of a small project site. Recently, the use of aerial photographs for hazard zonation has become popular. With such photos the mountainous terrain can be mapped quite easily though not exactly. These photos are available on 1:10,000 scales. The above two methods are aided by geophysical methods (Figure 6) to further investigate and understand subsurface geology.

Figure 6*: Geophysical survey (GPR).*

Mitigation strategy

The national development policies incorporate the problem of landslide. For every important project, be it the construction of a hydropower project or infrastructure development, the land stability is assessed first. Realizing the vulnerability of the terrain to landslides, generally the construction of buildings, bridges and other important infrastructure can begin only after the site has been approved for stability by the engineering geologists. Besides the Department of Geology and Mines, the Department of Road is also involved in mitigation of the landslide problems. Recently, every new road alignment is first thoroughly studied by the engineering geologists and landslide experts before the actual cuttings begin and in some places even environmental friendly roads have been constructed despite the huge cost. This was not done in the past. The advice of the concerned organizations are sought with regard to the geotechnical aspects. The Department of Geology and Mines caters geotechnical services to the other Government and private agencies.

Landslide mitigation strategies are applied to different types of landslides related to different geologic settings. These strategies include avoidance, stabilization, prevention and no action (live with recurring maintenance from landslide). Some of the common strategies to stabilize, control or prevent landslides include surface drainage and subsurface drainage as water is one of the main culprits of instability. Other strategies, especially for the roads and construction of infrastructure on the slopes include increase of resisting forces by retaining walls, soil reinforced earth and bioengineering of the disturbed slopes.

Mitigation interventions

Whenever a landslide or any other natural disasters struck a place, the Department of Geology is called up to assess the hazard and suggest mitigation measures. When the impact of the potential disaster (for example bursting of a landslide dam that can destroy a hydro-power project) is potentially too large, then the concerned authorities are called upon for a joint study team. The local community that is directly impacted by the natural disaster is usually informed of the impending danger. However, at present the community based initiative ends with informing the local authority of the likely hazard by the community members. The local authority in turn informs the central Government for action leading up to the mitigation works.

Capacity building and experience sharing

At present the society at large is not fully aware of the landslides or other natural hazards. The concerned organization, particularly the Department of Geology and Mines alone seems responsible for the mitigation of landslides. Therefore, there is a need to educate the public at different levels about the dangers of landslides. There needs a strategy that envisions a society that is fully aware of landslide hazards and routinely takes action to reduce both the risks and costs associated with those hazards. A comprehensive landslide hazard mitigation strategy that provides and encourages the use of scientific information, maps, methodology, and guidance for emergency management and land-use planning to reduce losses from landslides and other ground failure hazards nationwide needs to be developed. Geologists, engineers and decision-makers should be further trained in this regard.

The Department of Geology and Mines works closely with International Institute for Geo-Information Science and Earth Observation (ITC, Enschede and Delft, the Netherlands) and Norwegian Geotechnical Institute (NGI) regarding slope stability and environmental analysis. At present two long term experts from ITC, Delft are attachment with the Department and a joint project on geotechnical engineering is going on with NGI.

With regard to the glaciers in the northern parts of Bhutan, in the past the Department has work with International Centre for Integrated Development ICIMOD, Nepal on the dangers of Glacial Lake Outburst Floods (GLOF). Subsequently, a joint expedition venture was formed with the University of Vienna, Austria to monitor the potentially dangerous glacial lakes in Lunana. At present the glaciologist of the Department presently has a joint venture project with a team from the University of Kyoto, Japan and these glaciers and glacial lakes are monitored annually by field expeditions.

Recommendations

For effective land risk management, the potential landslide prone areas should be identified. In this light, the first thing that has to be done is to delineate susceptible areas and different types of landslides hazards at a scale useful for planning and decision making. At present the hazard prone areas are mapped on 1:50,000 scale, which is not really useful for micro-scale infrastructure development.

Further guidance and training ought to be provided regarding landslides not only to the geologists and engineers but also the decision-makers. The loss assessment from the landslide related hazards of the country and the economic impacts should be conducted to highlight the importance of such study. Public awareness and education with regard to the landslides is also of utmost importance.

Improper land use, for example quarrying for construction material without considering the conditions of the terrain, agriculture practices on steep slopes, irrigation on steep and vulnerable slopes, etc. should be avoided.

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Importance of Earthquake Induced Landslides in Landslide Hazard Mapping

R. K. Bhandari

Abstract

The time has come to take an unconventional view and perhaps even a highly controversial, provocative position and conclude that the landslide hazard mapping, the way it is done, is not really on the path to progress. The whole attempt to hazard mapping is pseudo-scientific, and as it surfaces time and again, all we have done so far is to rush in the enormous power of remote sensing and GIS to produce factor maps and then monotonically weave them in to hazard maps sidetracking several vital concerns. We seem to ignore hazards due to (a) past landslides, not obvious on the surface (b) earthquake-induced and earthquake-triggered landslides (c) runout effects of avalanches and earth flows (d) consequential landslides upon formation and bursting of landslide dams, where such possibilities can be foreseen (c) delayed, progressive failures, especially on unprotected deep cuttings and (d) visible part of unchecked urbanization and anthropogenic factors. What is more, by ignoring the essentiality of validation of inferred hazard maps against hard and soft ground truths, and by downplaying the user-friendly angle, we make matters much worse!

Most of the current landslide hazards mapping approaches are either blind or lame, or dumb, or at best on crutches. We have produced maps by limited ground surveys without an iota of appreciation for macro-geomorphology and remote sensing. Such maps are blind. We have produced maps by remote sensing with very little or no ground verification of truth. Such maps are lame. We have produced maps that will be hard to certify reliable because they have bit of both, but not enough. Such maps are on crutches. The user unfriendliness of the maps is reflected in their muteness to a development planner or a disaster manager. Further more; usually the scales of maps are not large enough to help either meaningful risk analysis, or imaginative development planning. The small-scale maps are usually over sung, as the non-scientists among us seem get lured and begin to question the need for further mapping when some such maps are already available. Wrapped with uncertainties, use of such maps may do more harm than good, and the mammoth effort built in the production of such maps may at best reduce to a mere academic exercise.

Since landslide hazard is strongly dependent on the degree, extent and rate of human intervention, and those are the hardest things to comprehend, judge and evaluate, the maps admittedly cannot be free from the ensuing limitations. Therefore, when it comes to slope failures, it would be wrong to replace the subjectivity and value judgment of the wise with all appealing sophistry of stochastic methods, and popular vote called consensus.

The paper spotlights the importance of earthquake-induced landslides in landslide hazard mapping and rakes up some of the hitherto neglected issues solely with the view to stimulate a debate to arrive at the way forward.

Keywords: Earthquake Induced landslide, Earthquake triggered landslide, Landslide Hazard Zonation Mapping.

Back to the basics

Earthquake events are usually known to stimulate pre existing landslides, and at times even trigger new ones. The commonest classes of the best-understood problems are flow slides due to liquefaction. The other possibilities are (a) reactivation of old, dormant or previously inactive landslides (b) accelerating known landslides (c) triggering of rock falls (d) development of fresh, first time landslides, and (e) onset of slumping and braking up of the ground. The understanding of the whole process presupposes understanding of (a) topographic and hydrological controls, (b) geological and geotechnical controls and (c) seismological controls.

Early model to explain earthquake-induced landslides was provided by Oldham (1899) while reporting on the 1897 Assam Earthquake. He considered section of a simple slope, covered by a soil mass (Figure1), which derived its stability through friction between itself and the underlying rock. According to him, when the underlying rock is set into motion by the shock waves of an earthquake, the surficial portion of rock will, at one period of the shock or the other, acquire outward motion. This motion will get communicated to the soil cap. In the next semi-phase of the wave, the movement of the surface of the rock will be inwards, but the inertia of the overlying soil cap will prevent the soil cap to respond instantly, and the consequence would be more or less complete loss of pressure of the soil cap on the rock. Oldham said "this reduction of pressure means a reduction of friction which alone prevents the soil cap from sliding bodily down the hill, and so a landslip is formed, where the reduction of resistance, and the slope of the hill, are sufficient to allow of it". That is how the threshold for slope failure is crossed, and a landslide follows.

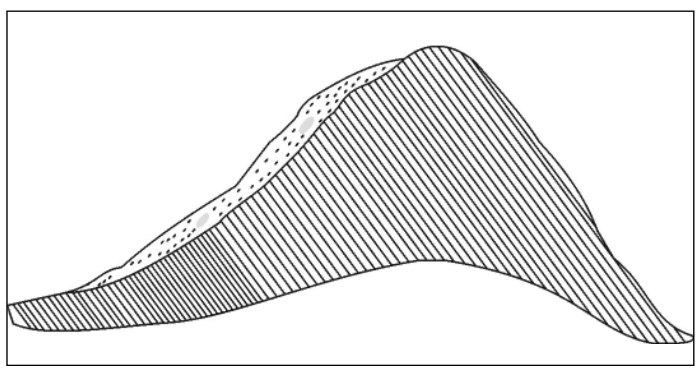

Figure 1: *Formation of Earthquake-induced Landslides (after Oldham, 1899).*

For landslide hazard mapping, a fair knowledge is essential to know about the behaviour of the ground at the foot of a slope that usually supports human settlements. Some insight in to it can be obtained by taking the example of alluvium along foot of a slope, Figure 2, Oldham (1899). A nearly vertical cliff 'a' of less than 2m height was known to have formed along the bases of the Khasi and Garo Hills. From the base of the cliff 'a' the alluvium was slightly depressed throughout 'b' from 3m to 6m wide, in which irrigation water

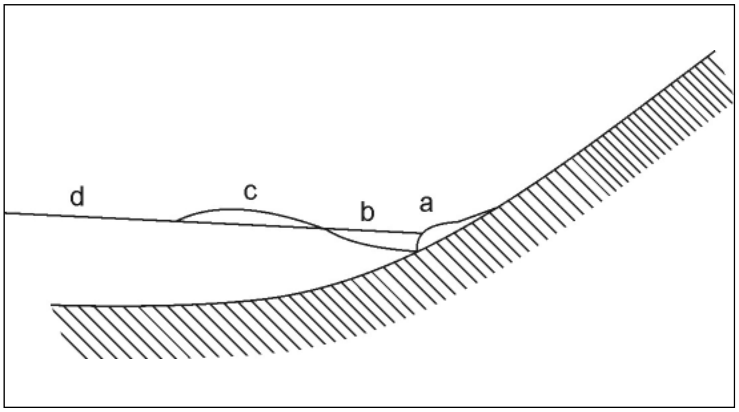

Figure 2: *Displacement of the alluvium along the foot of a slope, Oldham (1899).*

got stored. Beyond this was a mound 'c' raised above its original level, eventually merging in to plain'd'. Oldham explained that the thrust interaction of the hill and plain was responsible to raise the low ridge at 'c', while during the return movement; the alluvial soil between the ridge and the hill was lowered and broke away from the cliff.

Some of the observations (Bhandari, 2002) based on worldwide research effort, though not always very conclusive are presented below:

- No slope mass with a static factor of safety of 1.7 or greater has failed in an earthquake, no matter how large in magnitude.
- Steep sided bedrock ridges are generally subjected to more intense level of ground shaking than adjacent valleys are in the near field area, close to the source of shaking. An exception to this may come because of the amplification of the strong motion due to alluvium cover on the valley bottom.
- The response of a large ancient landslide to seismic forces is significantly modulated by number of strong motion cycles (duration of shaking) rather than by short-lived peak ground acceleration. With each cycle, more and more of seismic energy gets trapped in to the body of the slope, thereby robbing it of its elastic response, eventually causing local slippages, or thereafter a full fledged landslide.
- When a slope fails as a rigid body, the acceleration is assumed to be constant over the entire slope, and usually it refers to the horizontal component of the slope surface acceleration.
- Ground surface acceleration alone is a poor measure of the effect of shaking on slope stability, intensity even more so. Ground velocity, the experiences during the occurrences of large magnitude past earthquake events, and duration of shaking are considered to be better indicators of landslide susceptibility under seismic conditions. Critical acceleration of a slope is also an important factor in deciding seismic safety of a slope. The factor of safety during an earthquake may drop below one (limit equilibrium state) for a short duration of time, but the effect of failure on the slope may be negligible.
- Catastrophic landslide events are a post-seismic phenomena rather than a co-seismic happening. While the earthquake provides the trigger, the development of a landslide is seldom sudden, and is usually after the earthquake.
- A slope that exists in nature through a serious of past earthquakes is unlikely to fail unless provoked either by the unprecedented earthquake; or by its deadly combination with human intervention.
- Ground cracks produced by successive earthquakes serve as conduits for rain water and become sources of ground weakening in the long run of time.

- The limiting threshold for an earthquake induced landslide is MM Intensity IV-VI generated by an earthquake of magnitude 4 on the Richter scale.
- Area within which land sliding is generated tend to increase with the magnitude of earthquake shock, from less than 100 km^2 at magnitude 4, rising to about 500 km^2 at magnitude Mw=9.2
- Slope failures due to earthquakes are more frequent in convex slopes, where as those due to rainfall are more frequent in concave slopes, because of the associated hydrology.
- For slope failures due to earthquakes and rainfall, collapse tends to occur at the boundary of the heavily weathered and puckered stratum and the underlying base rock. Slopes near the shoulders of the terrain of high relief are more prone to seismic landslides.
- If there are two slopes of different slope angles but equal factor of safety, the gentler slope will fail under smaller acceleration than the steeper one. The following relation tells it all:

$a_{max}/g = [(C_d/C_s)\ F_s\ @1]\ \tan_{av}$ in which:

a_{max} = peak acceleration
α_{av} = average slope angle
C_d = Cohesive strength of soil under dynamic loading
C_s = Cohesive strength of soil under static loading

Earthquake induced first time landslides are few and far between. They can be predetermined not so much by remote sensing but by a thorough seismo-tectonic and geomorphologic field mapping in the backdrop of remote sensing data. In a great majority of cases, earthquake triggers pre-existing but dormant landslides due to the earthquake shock and subsequent aftershocks. Some of them may also occur hours and days after the shock. According to Keefer (1984), rock fall, rock avalanches, rockslides and soil slides are the commonest forms of landslides, which get triggered when the limiting thresholds for slope failure get crossed. Threshold conditions of various types of seismically generated mass movements and their relative abundance are presented in Tables 1 and 2. Keefer believed that the extent of area within which land sliding is generated tends to increase with shock magnitude, from less than 100km^2 at Magnitude 4, to about 500,000km^2 at Magnitude of 9.2; the influence zone gets modified by external factors such as ridges, convex hills and escarpments.

The Indian Examples

There are numerous examples of earthquake related landslides. The Assam Earthquake of 1950 caused landsliding over 15000 km^2 of the eastern Himalaya, involving an estimated total displacement of 50 billion cubic metre of material due to tens of thousands of landslides, (Kingdon Ward, 1955). The Uttarkashi earthquake of 20th October 1991 of Magnitude 6.6 on Richter scale; and its aftershocks did trigger over 200 large and sever hundred smaller landslides, Table 3.

***Table 1**: Threshold conditions of various types of seismically generated mass movement and relative abundance (Keefer 1984)*

Type of mass movement (Varnes 1978, 1984)	Threshold earthquake magnitude	Common threshold scale MM intensity	Minimum threshold scale MM intensity	Abundance in 40 documented earthquakes
Rock falls	4.0	VI	IV	$>10^5$
Rock slides	4.0	VII	V	$>10^5$
Disrupted soil slides	4.0	VI	IV	$>10^5$
Soil falls	4.6	VI	IV	10^3 - 10^4
Soil block slides	4.5	VII	V	10^2 - 10^3
Soil slumps	4.5	4VII	V	10^4- 10^5
Soil lateral spreads	5.0	VII	V	10^4- 10^5
Rock slumps	5.0	VII	V	10^3 - 10^4
Rapid soil flows	5.0	VII	V	10^3 - 10^4
Rock block slides	5.0	VII	V	10^3 - 10^4
Slow earth flows	5.0	VII	V	10^2 - 10^3
Sub aqueous slides	5.0	-	-	10^2 - 10^3
Rock avalanches	6.0	VI	IV	10^2 - 10^3
Soil avalanches	6.5	VI	IV	10^2 - 10^3

***Table 2**: Relative Abundance of Earthquake Induced Landslides*

Very abundant (more than 100,000 in the 40 earthquakes)	Rock falls, disrupted soil slides, rock slides
Abundant (10,000 to 100,000 in the 40 earthquakes)	Soil lateral spreads, soil slumps, soil block slides, soil avalanches
Moderately common (1000 to 10,000 in the 40 earthquakes)	Soil falls, rapid soil flows, rock slumps
Uncommon (100 to 1000 in the 40 earthquakes)	Sub aqueous landslides, slow earth flows, rock block slides, rock avalanches

Sah and Bartarya (2002) has reported distribution of landslides in the Chamoli-Rudraprayag districts of Garhwal Himalaya, triggered by Chamoli earthquake (Magnitude 6.8 on Ricter Scale) of March 29, 1999, Table 4. It is yet to be established as to what was the superposed impact of the Bihar-Nepal earthquake of 1934 (Magnitude 8.3 RS) and of 1988 (Magnitude 6.5 RS), both of which had occurred in the Main Boundary Thrust, not too far outside.

The Debate on Nomenclature

The terms earthquake-induced and earthquake-triggered landslides are interchangeably being used robbing scientists of the precision with which the facts are to be expressed. Unstable slopes, for in-

***Table 3**: Landslides induced by Uttarkashi Earthquake of 1991*
(Source: Survey of India Publication 30)

Sector	Description
Tehri-Uttarkashi	Ground fissures were seen along the riverbanks. Rock masses were found to get dislodged in the highly jointed quartzite formations.
Uttarkashi - Kanaudia Gad	Numerous landslides occurred in the terrain composed of river borne materials, as well as in the rock outcrops. Around Maneri, vast areas of slopes failed. Major rockslide occurred in the bank road of the Maneri Dam. Several old landslides were reactivated causing road damage. In whole of this sector, the formation of the road was extensively damaged.
Gangari - Aghora	About 59 cases of rock dislodgements and two major landslides were recorded, 12 km apart.
Dharasu - Barkot	Rock dislodgements were reported in this sector.
Uttar Kashi - Kishanpur Sukinidhar	About 41 cases of rock dislodgements and 6 landslides were reported. The riverbanks cracked and consequently high retaining walls collapsed.
Bhaldiyana - Sukinidhar	10 rockslides were reported. Additionally large number of rock dislodgements was also reported.
Dhanutri – Kamand	A number of landslips occurred mostly in the overburden material and riverbanks cracked and subsidence was wide spread.
Kund - Gauri Kund	This sector experienced a number of rock dislodgements and a few landslides and ground fissures.
Tilwara - Chirbatia	No landslides were reported. About 15 -20-rock dislodgement incidences were reported from this sector.

stance those which are virtually at the state of limit equilibrium and are on the verge of sliding get the provocation to slide by the earthquake trigger, and could be classed as earthquake triggered landslides.

We have a wide range of old, gravity induced landslides, which may get provoked by the earthquake shock, as the last straw on a camel's back. Such slides are also better classed as earthquake triggered landslides. Similar argument can be advanced for rain induced landslides, gravity being the principal force operating at all times.

On the otherhand, it is not unlikely that even seemingly stable slopes with unfavourable discontinuities or shear zones may get dislodged by a massive earthquake shock. It would be more appropriate to class such slides as earthquake induced landslides.

Studies consequent to the Uttarkashi earthquake, especially with respect to pre and post earthquake imagery, revealed 70 new slides, in addition, to reactivation of 16 old slides. In such as a situation, further studies of 70 new slides alone could have substantiated beyond doubt that all the 70 slides were indeed first time slides, and not those which lay dormant for centuries under the veil of grass.

***Table 4**: Distribution of earthquake induced landslides in Chamoli-Rudraprayag Districts, Garhwal Himalaya, after Sah and Bartarya (2002)*

Area and road section	Type and dimension of slope failure														
	<5m			>5m-10m			>10m-25m			>25m		Un	S_u	Re per km^2	Slide per km.
	DF	RF	DS	DF	DF	DS	DF	RF	DS	DF					
1. Nandprayag to Chamoli (12 km)	24	21		5		4	1			3	4			1	2.76
2. Chamoli to Gopeshwar (9 km)	5	3										6			2.51
3. Gopeshwar to Mandal (12 km)	17	5		1			3			1		1		1	2.02
4. Chamoli to Pipalkoti (16 km)	26	6		4		1		2				1	1	2	1.02
5. Pipalkoti to Langsi (15 km)	16	35		2			4					2	3	9	3.64
6. Langsi to Joshimath (18 km)	8						1							3	0.49
7. Nandprayag to Langasu (10 km)	4	14		1										1	1.87
8. Langasu to Karanprayag (10 km)	4	1		1											0.34
9. Karanprayag to Rudraprayag (32 km)	2	7	2									4			0.10
10. Rudraprayag to Chandrapuri (27 km)	2			2	1		1						1	1	0.15
11. Banswara to Akhori (16 km)	13	1												1	0.44
12. Bheri to Guptakashi (15 km)	5	1		1										1	0.19
13. Bheri-Makkuband to Okhimath (52 km)	12	1	2	4	1								1		0.38
14. Makkuband to Mandal (43 km)	3													2	0.90
15. Gopeshwar to Sirupani (25 km)	9			3			4						1		0.50
16. Sirupani to Pokhri (35 km)	17			2			1							3	0.29
17. Pokhri to Rudraprayag (52 km)	6									1					0.11

***Note**: RF=rock fall, DS=Debris slide, DF=Debris fall, UN=Undermining of roads, Su=Subsidence, Re=Reactivation of existing slides.*

In a recent study, Ravindran and Philip (2002) have reported major landslides in and around Chamoli identified on Satellite pictures, Table 5.

***Table 5**: Major Landslides in and around Chamoli Identified on Satellite Data (after Ravindran and Philip) 2002.*

Sl. No.	Location	Number of Landslides	Dimension of the landslide	Type of landslide
1.	North of Joshimath	One	Medium	New landslide
2.	Around Gopeshwar Township	Four	Medium to large	New landslide
3.	Ghingran	One	Large	Reactivation of the old slide
4.	Vishnupuram	One	Medium	New landslide
5.	North of Garigaon	One	Large	Reactivation of the old slide
6.	Gauna	One	Large	Reactivation of the old slide
7.	South of Garigaon	Two	Medium	New landslide
8.	North of Gwar	Two	Small	Reactivation of the old slide
9.	North of Kanjaun	Three	Small	New landslide
10.	Dumak	One	Large	New landslide
11.	North of Kimana	One	Small	New landslide
12.	Southeast of Jakhala	Two	Small	New landslide
13.	Southwest of Nandprayag	One	Medium	Reactivation of the old slide
14.	Kande Village	Two	Medium	New landslide
15.	North of Oring	One	Medium	New
16.	Siron	One	Medium	New
17	Rauta	One	Medium	New

Here, the fundamental issue raises its head again. Are the new landslides really new, on the undisturbed virgin slope? This question can be answered only by site specific slope studies, in the backdrop of the historical data. The terrain change studies reported by Kimothi et al. (2002) using IRS IC/ID data, can provide deep insights into the genesis of earthquake related landslides, Table 6. Also, the collateral studies such as those reported by Sah and Bartarya (2002) with respect to the impact of Chamoli earthquake on hydrological regime are also worthy of note, Figure 3.

***Table 6**: Terrain changes after earthquake (based on analysis of pre and post IRS IC/ID LISS III/PAN data and field check*

Name of the Block	**SOI topo-graphical map no.**	**Pre-earth-quake land-slides (Nos.)**	**No of post Earthquake Landslides (Nos.)**			
			New LS	Old reacti-vated LS	Fissures/ cracks	Spring dis-charges
Pokhari, Augustmuni, Okhimath	53N/3	80	36	2	1	1
Dasholi, Joshimath	53N/7	90	62	11	3	2
Dasholi, Joshimath	53N/6	20	6	3	-	-
Joshimath	53N/10	35	5	1	-	-
Total		225	109	17	4	2

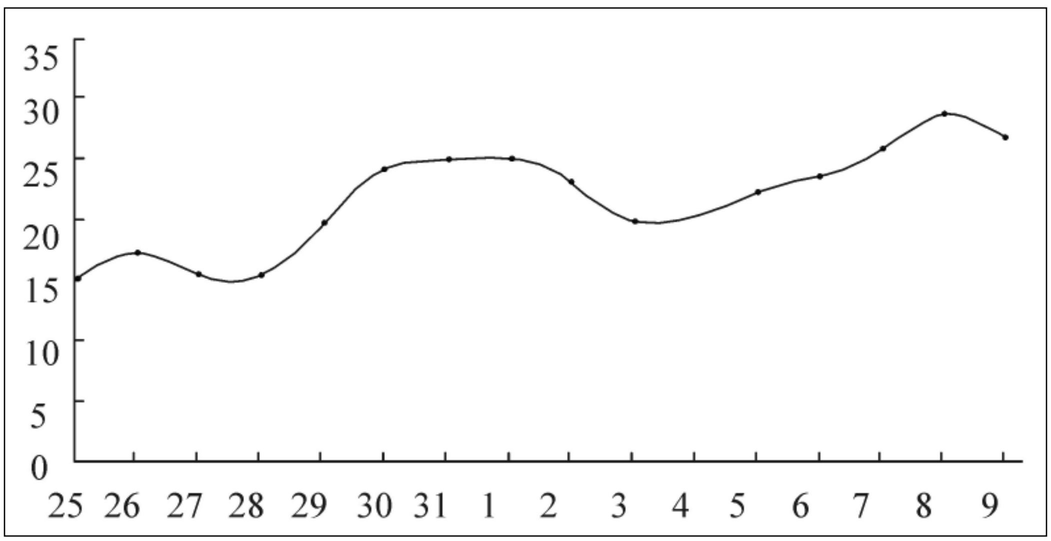

***Figure 3**: Daily discharge of Mandakini River recorded at Chandrapuri showing the impact of earthquake on the hydrological regime of the area (after Shah and Bartarya, 2002).*

Concluding Remarks

Scientific studies involving, mapping of pre and post earthquake scenarios, seismo-tectonic and Geo-technical mapping, isoseismal patterns, contours of response spectra are all important in developing basic understanding of earthquake related landslides. The future landslide hazard mapping programmes should take cognizance of such possibilities alongside other hitherto neglected factors outlined in the paper.

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An Overview of Landslide Hazard in Nepal Himalaya

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Abstract

Because of location, rugged mountain topography, variable climatic condition, complex and fragile nature of the geological structure with active tectonic processes, high intensity rainfall in monsoon and continued seismic activities, Nepal Himalaya is susceptible to earthquake, landslide, flood, soil erosion and other natural disasters. Among the various natural disaster, landsllide is the major natural disaster in Nepal responsible for the huge loss of life, property, and damage to the infrastructure alongwith the degradation of the environment. Consequently, the economy of the country is severely strained because of the extensive rehabilitation work to be carried out. Although country is continuously suffering, it has not yet initiated adequate efforts towards landslide risk reduction. In this regard, landslide hazard mapping is found to be the useful tool for delineation the areas susceptible to sliding so that risk reduction measures can be adopted on time. In general, two methods are in use (a) superimposition and, (b) GIS based biverate statistical methods. Because of its simple procedure and adequate precision, the superposition method is being widely used to get first order information on landslide hazard zonation in Nepal. Similar to other parts of the Himalaya, the main factors causing landslide hazard in the Nepalese Himalaya are steep slope, improper land use pattern, rock types and associated discontinuity, soil type and depth and rampant urbanization. The high hazard zones for rock slopes are confined to slopes with steeply dipping fractured rocks whereas soil slope hazard is confined to fault zones and south facing slopes. In Nepalese Higher Himalaya, soil slope processes are more severe than rock slope processes. In the present scenario of hazard level, Nepal should come up with strong institutional development integrating professional from different disciplines (geology, geophysics, engineering, environment, hydrology, sociolgy etc) for overall research work, mitigation, preparedness, and education on landslide disaster.

Key words: Landslide, Nepal Himalaya, Hazard mapping, Superimposition method.

Introduction

Nepal is located in the central part of the Himalayan arc and occupies 800 km out of 2400 km of its length. About 83% of the country is mountainous terrain and only 17% in the south lies in the plain area called Terai. Because of its location, rugged mountain topography, variable climatic conditions, complex and fragile nature of the geological structure with active tectonic processes, high intensity rainfall in the monsoon period and continued seismic activity, the country is prone to various types of natural disasters such as landslide, soil erosion, flood and other mass wasting phenomena. The steep gradient of Himalayan rivers with their high water flow is also significantly contributing to the process of landsliding and related mass wasting phenomena. Apart from these, inadequate geological investigation during road construction has also induced many landslides along the major highways of Nepal.

Many villages in Nepal are located on or adjacent to riverbanks, unstable slopes and old landslides, and are vulnerable to landslides and associated phenomena. Similarly, linear infrastructures are also vulnerable to slope instabilities due to their spread along the long lengths of a variety of terrain, unfavourable geological conditions and surface and ground water conditions. Therefore, in recent years cases of loss of life, property and infrastructures damaged by the landslides have increased tremendously. The economy of the country has been seriously strained because of the extensive rehabilitation works to be carried out every year. A significant reduction of menace can be achieved by the systematic study of mass movements and using hazard maps, which predict the relative degree of hazard in a given area. The aim of this paper is to communicate the present scenario of landslide disaster and status of hazard mapping in Nepal Himalaya taking part of Higher Himalaya in eastern Nepal as an example.

Physiography

Himalaya, the youngest mountain chain on the globe, is a result of ongoing continent-continent collision that has started since last 50 Ma. It is composed of rock-masses which have a high degree of fragility and a greater tendency to undergo accelerated weathering and decomposition under the influence of environmental factors. Being located in the central part of the Himalayan arc Nepal shares almost similar structural, geological, tectonic, climatic and geomoprhological characteristics with other parts of the Himalaya. With 83% low to high mountainous area, Nepal covers approximately one third of the Himalayan mountain ranges in the central part. Similar to the entire Himalayan arc, the Nepal Himalaya has eight well defined longitudinal geomorphologic zones (Table 1, Figure 1) characterized by their own unique altitudinal variation, geology, slope and relief characteristics, and climatic pattern. They are from south to north (1) Terai; (2) Siwalik (Churia) Range; (3) Dun Valleys; (4) Mahabharat Range; (5) Midlands; (6) Fore Himalaya; (7) Higher Himalaya; and (8) Inner and Trans Himalayan Valleys (Hagen, 1969). Nepal shows unique variation in elevation i.e. 60 m in the south to 8848 m in the north within 150 km of her width. Among these physiographic divisions, Siwalik, Mahabharat Range and Midlands shares considerable numbers of landslides events.

Geology

The geo-tectonic framework of the Nepal Himalaya is governed by three northerly dipping major thrusts system, namely from north to south, the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Main Frontal Thrust (MFT). These thrust faults distinctly demarcate four tectonic packages of rocks, from north to south they are the Higher Himalayan sequence, Lesser Himalayan sequence, Siwalik Zone, and Terai Zone (Figure 2). The MFT on the south separates the sedimentary rocks of the Sub-Himalayan (Siwalik) sequence generally composed of mudstone, sandstone and conglomerate and the alluvial deposits of Gangetic Plains called Terai. The MBT separates the low grade metamorphic rocks (phyllite, slate,

***Table 1**: Physiographic division of Nepal Himalaya.*

No.	Geomorphic unit	Width (km)	Altitude (m)	Main rock type	Age
1	Terai (Northern edge of the Gangetic Plain)	20-50	100-200	Alluvium: coarse gravels in the north near the foot of the mountains, gradually becoming finer southward. Foreland basin deposits	Recent
2	Churia Hills (Siwalik equivalent rocks)	10-50	200-1000	Sandstone, mudstone, shale and conglomerate. Mollase deposites of the Himalaya.	Mid-Miocene to Pleistocene
3	Dun Valleys	5-30	200-300	Valleys within the Churia Hills filled up by coarse to fine alluvial sediments	Recent
4	Mahabharat Range	10-35	1000-2500	Schist, phyllite, gneiss, quartzite, granite and limestone belonging to the Lesser Himalayan Zone	Precambrian and Paleozoic, occasionally also Cenozoic
5	Midland	40-60	200-2000	Schist, phyllite, gneiss, quartzite, granite, limestone geologically belonging to the Lesser Himalayan Zone.	Precambrian and Paleozoic to Mesozoic
6	Fore Himalaya	20-70	2000-5000	Gneisses, schists and marbles mostly belonging to the northern edge of the Lesser Himalayan Zone	Precambrian
7	Higher Himalaya	10-60	> 5000	Gneisses, schists and marbles belonging to the Higher Himalayan Zone	Precambrian
8	Inner and Trans Himalayan Valleys		2500-4000	Gneisses schists and marbles of the Higher Himalayan Zone and Tethyan sediments (limestones, shale, sandstone etc.) belonging to the Tibetan-Tethys Zone	Precambrian and Cambrian to Cretaceous

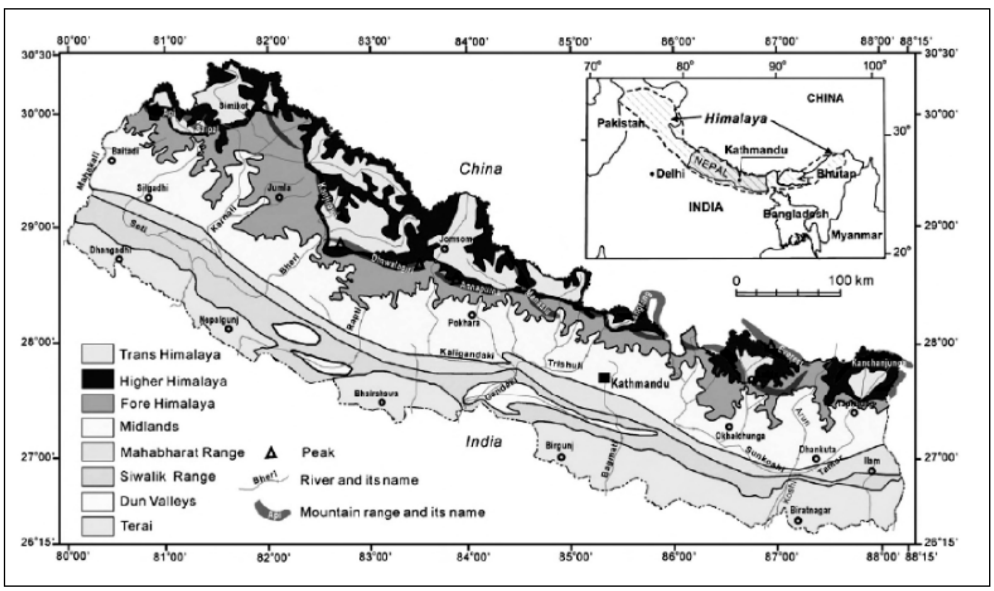

***Figure 1**: Regional geomorphic map of Nepal (modified after Hagen, 1969. Adopted from Dahal and Hasegawa, 2008). Inset shows location of Nepal in the Himalaya.*

quartzite, schist etc) of the Lesser Himalayan sequence and the Siwalik sequence. Similarly, the MCT is a boundary between the high grade metamorphic rocks (schist, gneiss, granite etc) of the Higher Himalayan sequence and the Lesser Himalayan sequence. Moreover, the South Tibetan Detachment System (STDS), a north dipping normal fault system, marks the boundary between the Higher Himalayan sequence and the overlying sedimentary sequence (limestone, shale etc) of the Tibetan–Tethys Himalaya (Figure 2).

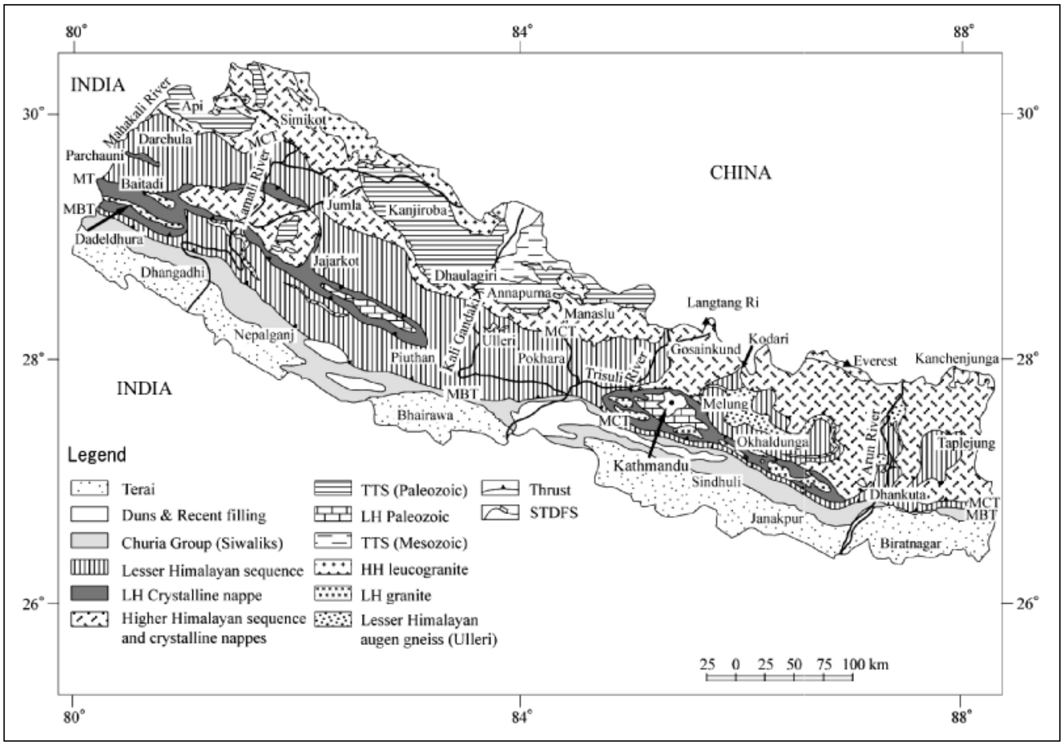

Figure 2: *Geological map of Nepal (modified after Upreti and Le Fort, 1999). LH, Lesser Himalaya; HH, Higher Himalaya; TTS, Tibetan-Tethys sequence; MBT, Main Boundary Thrust; MCT, Main Central Thrust; MFT, Main Frontal Thrust; STDS, South Tibetan Detachment System.*

Precipitation

Rainfall is one of the important causative factors to trigger the instability on the mountain slope. The magnitude of influence, however, also depends on topography of the area, geological characteristics of the slope, porosity and permeability of the rock and soil. Equally, variation in soil depth and nature of discontinuities on rock mass also affect the stability of the slope. The climate of Nepal is basically controlled by monsoon winds and physiography. The monsoon winds in south Asia generally result from an inland low pressure that develops in summer. They are accentuated by a northward migration of air from the southern hemisphere. These south to southwesterly winds in Nepal are responsible to monsoon rainfall. In Nepal, rainy season starts in June and continues for until September. Generally, precipitation decreases from east to west during summer monsoon whereas reverse trend is observed in winter season. About 80% of the total precipitation occurs between June and September with relatively low precipitation from November to February. The rainfall brought by these monsoon winds are characterized by strong seasonality, variation in amount of precipitation, and high intensity in

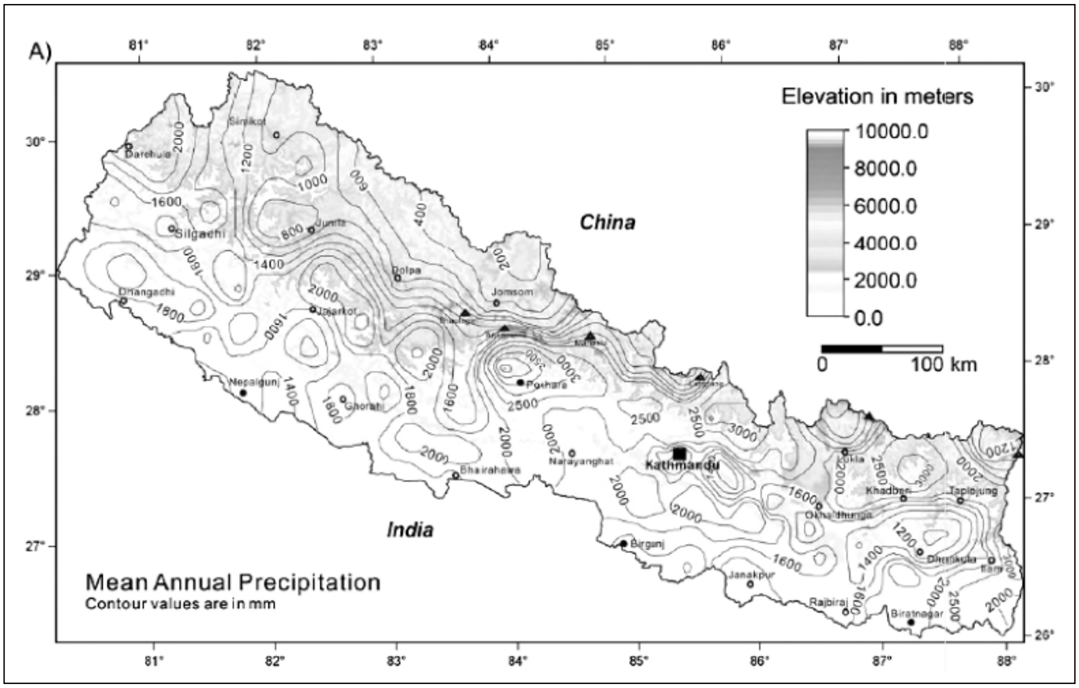

***Figure 3**: Mean annual precipitation in Nepal. Note that peak values are around eastern and central Nepal (modified after DHM, 2003). Adopted from Dahal and Hasegawa (2008).*

lower altitude. The rainfall distribution map (Figure 3) of Nepal generally shows three distinct zone of high mean annual precipitation (> 2500 mm). These are located to south of Ilam in eastern Nepal, and Kathmandu and Pokhara in central Nepal. The mean annual precipitation in Nepal Himalaya varies from approximately 250 mm in north of the Higher Himalaya to 3000 mm in other stations to the south of the Higher Himalaya. The mean annual precipitation was 1627 mm (Alford, 1992). Interestingly, in Nepal it is common for 10 per cent of total annual precipitation to occur in a single day and 50 per cent of total annual precipitation in 10 days in a rainy season. A distinct rain shadow zone exists north of the Higher Himalaya. Generally, the inner Himalaya and valleys are dry. Locally, the rainfall pattern in Nepal is controlled by mountain slope aspects. The south facing slopes are getting more precipitation than the north facing slopes. This uneven precipitation pattern has accelerated frequency of landslide in Nepal.

Distribution of landslide in Nepal

In Nepal, systematically recorded landslide data are rarely available. This is mainly because no specific organization with technical personnel in Nepal is responsible for recording landslide events. The Ministry of Home Affairs (MoHA) has been collecting and publishing data on both natural and man-made disasters. But landslide and flood disasters have been recorded as the same event. Similarly, the Department of Water Induced Disasters Prevention (DWIDP) and the Department of Mines and Geology (DMG) have been working on landslide studies. Various reports on landslides are published by these organizations, but they lack adequate information on landslide occurrence date and time and corresponding rainfall. The DWIDP publishes its annual bulletin with annual landslide disaster information. Recently, the Nepal Red Cross Society (NRCS) has also started to prepare an annual disaster database in Nepal.

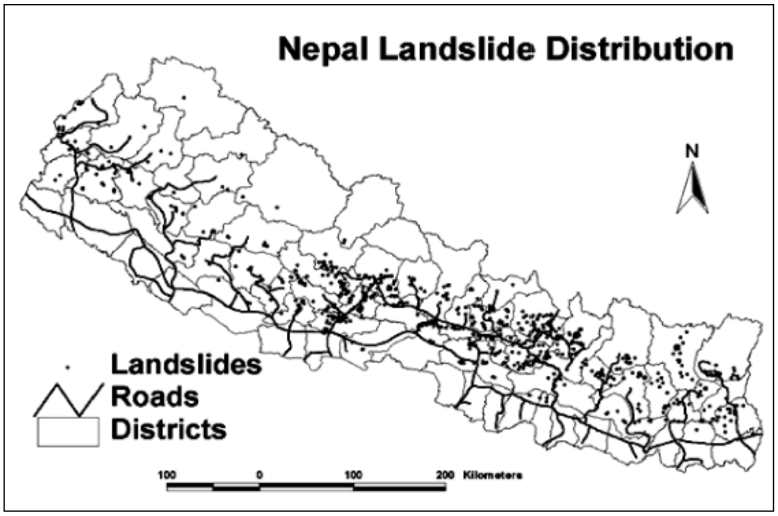

***Figure 4. Landslide distribution in Nepal (Source**: Durham University).*

Although data base is limited and for short duration, the distribution of landslides across Nepal shows uneven pattern (Figure 4). In general, the density of fatal landslides is low for the Terai districts and for the mountain districts in the northwest of the country (Figure 4). The density is highest for the hill districts, especially in the central and eastern parts of the country. There is also an area of higher density in the hill districts in the western part of Nepal. This distribution is primarily by a combination of relief and precipitation. The Terai districts mostly comprise flat plains, upon which landslides are not common. In the hill and mountain districts, the distribution correlates with the annual precipitation, for which the highest levels are in the hill districts, especially in central and eastern Nepal (compare Figures 3 and 4). In general, majority of landslides are concentrated in the Midlands and the Fore Himalaya. Among them, many landslides are confined along the stretch of major highways of Nepal. This is mainly due to adverse geological condition and inadequate geological investigation. Further, because of fragile nature of geology and structure, landslides are also associated with the main tectonic zones i.e. MCT, MBT and MFT. However, due to lack of proper institution, inaccessibility and adverse topography, still numbers of landslides have not been reported precisely.

Damage caused by landslide in Nepal

In Nepal, as mentioned before, the predisposing factors for landslide occurrence and other slope instabilities are the inherent geological condition and steep slope gradients, excessive rainfall, earthquakes, and various anthropogenic causes. In general, the years with excessive rainfall or large cloudbursts experience the highest numbers of landslide. About 298 people were killed annually (Table 2) in Nepal. In 1993, a record year, landslides and floods killed 1,336 people in central Nepal only (Figure 5).

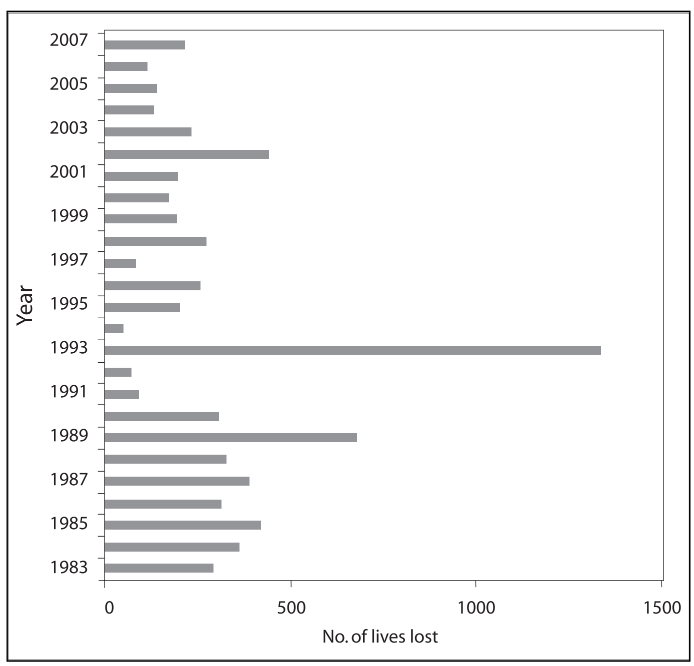

***Figure 5**: Total loss of life due to landslide and flood from the year 1983-2007. (Source: Ministry of Home Affairs).*

***Table 2**: Damages caused by landslide and floods (1983-2007). (Source: Ministry of Home Affairs).*

Year	People		Livestock Loss (Nos.)	Houses Destroyed (Nos.)	Affected Family (Nos.)	Land Affected (ha)	Estimated Loss (Million NRs.)
	Death	Injured					
1983	293	NA	248	NA	NA	NA	240
1984	363	NA	3114	7566	NA	1242	37
1985	420	NA	3058	4620	NA	1355	58
1986	315	NA	1886	3035	NA	1315	16
1987	391	162	1434	33721	96151	18858	2000
1988	342	197	873	24 81	4197	NA	1087
1989	700	4	297	6203	NA	NA	29
1990	307	26	314	3060	5165	1132	44
1991	93	12	36	817	1621	283	21
1992	71	17	179	88	545	135	11
1993	1336	163	25425	17113	85254	5584	4904
1994	49	34	284	569	3697	392	59
1995	246	58	1535	5162	128540	41867	1419
1996	262	73	1548	14037	36824	6063.4	1186
1997	87	69	317	1017	5833	6063.4	104
1998	273	80	982	13990	33549	326.89	969
1999	209	92	309	2538	9768	182.4	365
2000	173	100	822	5417	15617	888.9	932
2001	173	120	796	5229	15348	620	919
2002	196	88	377	2995	26303	NA	251
2003	441	265	2024	13996	38859	NA	416
2004	232	76	865	2683	7167	NA	234
2005	131	24	495	2552	14238	NA	219
2006	141	31	360	1090	2088	NA	131
2007	216	45	21553	10002	114668	500.3	183
Total	**7460**	**1736**	**69131**	**157500**	**645432**	**86808.29**	**15834**

**1 Million NRs=US$ 14286*

It is estimated that from the year 1983 to 2007, NRs 15834 million was lost, about 86525.29 hectares land was affected, and 157500 houses were damaged due to landslide and flood in Nepal (Figure 6). The damage caused by the landslides and floods of 1993 was about NRs. 4904 million in the 5 most affected districts among a total of 43 districts which had undergone through the impacts of it. This figure is equivalent to about 3 % of the country's annual budget of that year. Besides disruptions of normal life of the Nepalese, the loss due to landslide and flood was 24 % of the total export earnings and 27 % of the gross fixed capital formation. It was estimated that the floods of 1993 retarded the country's development performance by at least two decades.

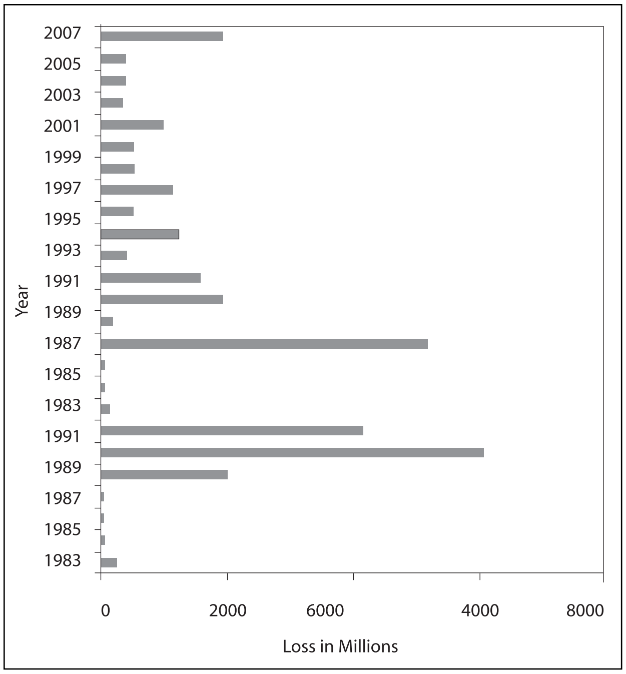

Figure 6 *: Economic loss from different disasters from 1983-2007.*

Landslide hazard mapping: A Nepalese scenario

Although the people of Nepal are suffering from the landslides at a large scale, systematic study of the landslide including landslide hazard mapping and risk assessment has not properly been done. Most of the studies are confined either to the individual cases or hazard prone sector of the linear infrastructures and are of preliminary type. Department of Mines and Geology has carried out landslide hazard mapping in major cities of Nepal e.g. Bhairahawa, Syangja, Butwal, Pokhara, Kathmandu, Hetaunda, Dharan etc. Many other cities are under investigation. However, very few works have been done for hazard mitigation and disaster management. In Nepal the area of investigation, adopted methodology and the classification schemes followed by the investigators differ considerably. Therefore, it is essential to follow more suitable, feasible and precise methodology for landslide studies.

Various methods of hazard assessment have been proposed and used in Nepal viz. Kienholtz et al. (1984), Wagner et al. (1990) Deoja et al. (1991), Dhital et al. (1991), Sikrikar et al. (1998), Dangol and Ulak (2002). Upreti and Dhital (1996) summarized various examples of landslide hazard mapping throughout the country. Though several methods are available for landslide hazard mapping, the superposition method proposed by Deoja et al. (1991) has been widely applied in landslide hazard mapping in Nepal. This method requires preparation of thematic maps, which deal with natural states such as engineering geological conditions, slope, hydrological as well as land use condition. For such maps data are acquired by the study of aerial photographs, topographical and geological maps, previous literatures and fieldwork. The landslide hazard map is finally prepared by superimposing all thematic maps and other relevant data.

Recently, with the advent of modern techniques, computer aided landslide hazard mapping has also been introduced in Nepal. Wagner et al. (1990) developed the program "SHIVA" to make soil and rock hazard maps. In this method, slope angle, lithology, rock structure, soil type, soil depth, hydrology, land use pattern are considered. Dangol et al. (1993) prepared the hazard map using the software "SHIVA". In the recent years, use of Geographic Information System (GIS) has been increasing constantly for landslide hazard assessment (e.g. Dangol and Ulak, 2002; Ghimire, 2000; Carrara et al., 1991).

Case study from eastern Nepal Higher Himalaya

Landslide hazard mapping invokes a multidisciplinary approach integrating all the influencing factors on slope instability in the study area (Uromeihy, 2000). It is an important tool for data base preparation, risk assessment, and landslide disaster management. The landslide hazard maps provide required knowledge of landslide susceptibility condition of a certain region, which is useful for the community in planning, mitigating, and avoiding the threats of landslide. On the other hand, the landslide hazard maps of a specific site are prepared for landslide monitoring as well as for delineating areas requiring mitigation measures. It is based on the assumption that the landslides occur as a result of similar geological, geomorphologic and hydrological conditions that led to past and present landslides. The landslide hazard map not only shows the hazard level but also deals the major type of failure, its extent, and direction of the movement. In this section, a case study from eastern Higher Himalaya is taken to communicate widely adopted methodology in Nepal for landslide hazard mapping.

For the hazard assessment, the superposition method developed by Deoja et al. (1991) was used because of simple procedure and adequate precision. For this purpose, thematic maps such as geological map, slope map, engineering geological map, landuse map, and the morphostructural map were prepared to get site condition. For collection of data, field survey was conducted giving emphasis on:

- General understandings of the geology and landslides,
- Detailed data collection of large and small landslide sites such as type of failure, slope angle and direction and hydro-geological condtion,
- Investigation of unstable sites, deposits and gullies, which may become the source of sediments,
- Verification of land use pattern, and
- Collection of other necessary data for hazard mapping

First, base map was divided into several slope facets, which are restricted by ridges and rivers. The relative hazard map was prepared by adding ratings for various hazard components. The area covered by soil and rocks were rated separately using specific rating values developed for Nepal Himalaya (Deoja et al., 1991). The landslide hazard map was then prepared by superimposing all the thematic maps separately (Figure 7). Finally, all the rating values attributed to each hazard component are summed up and hazards are categorized into the low, medium and high hazard on the basis of the total rating value of each facet. In this method, soil slope hazard and rock slope hazard maps are separately prepared. The geology, geomorphology, landslide distribution of the study area is briefly described below.

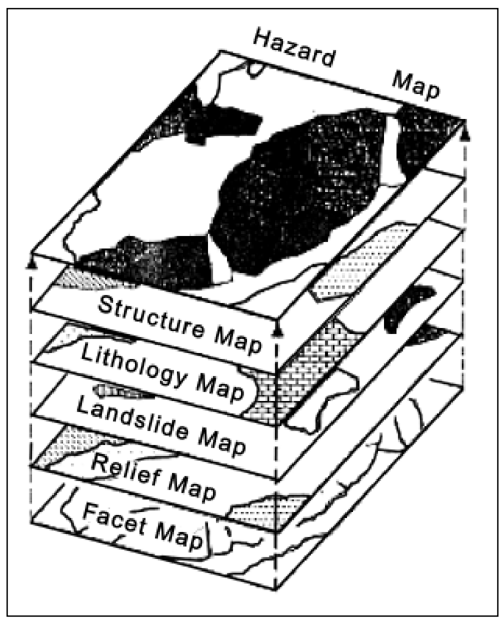

***Figure 7:** Conceptual idea of superimposition method of landslide hazard mapping.*

Geological setting

Geologically, the study area lies in the southern part of the Higher Himalaya, where the Higher Himalayan Crystallines have been thrust over the Lesser Himalayan metasediments along the MCT (Schelling, 1992). Geology of the study area is mainly dominated by the Precambrian to Cambrian kyanite and sillimanite bearing gneisses, schists, metaquartzites, calcsilicate gneisses, orthogneiss and augen gneiss (Figure 8). The Higher Himalayan Crystallines (Mahabharat crystallines of Schelling, 1992) of the eastern Nepal are apparently continuous with the Darjeeling gneisses of the Sikkim Himalaya (Auden, 1935; Gansser, 1964).

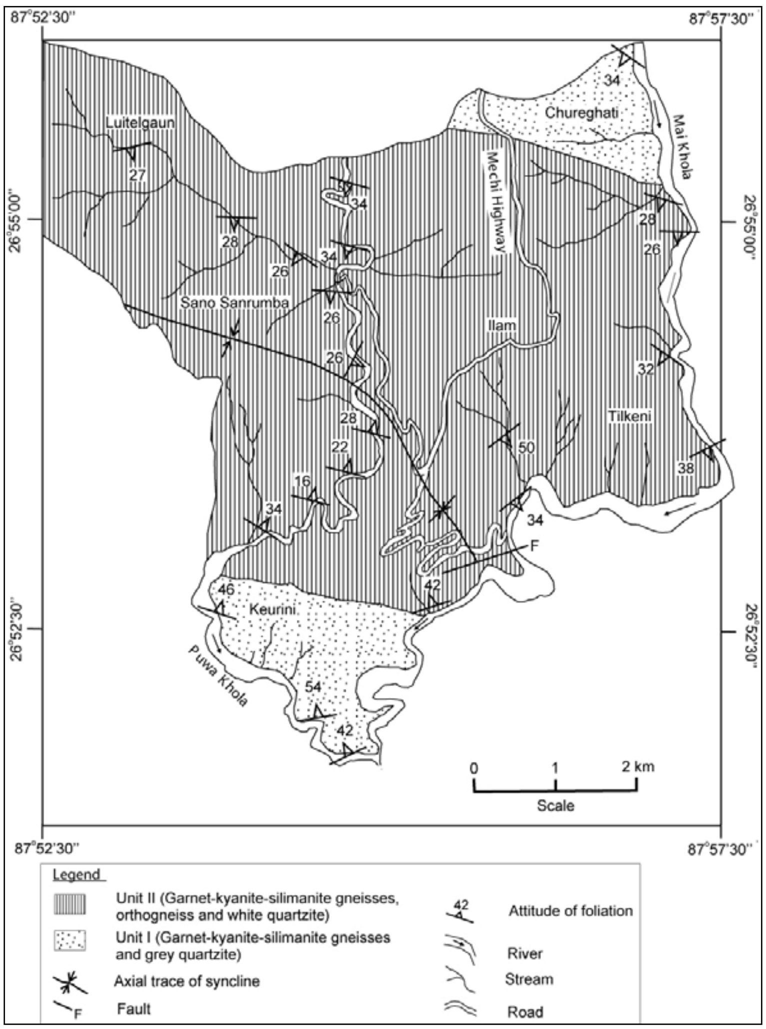

Figure 8: *Generalized geological map of Ilam area.*

Geomorphology and drainage

The area is characterized by the varied topography. The landform is mainly controlled by tectonic processes and subordinately by mass wasting processes. The erosional landforms predominate over depositional ones. Rugged hills, numerous deep gorges along the Puwa Khola, steep slopes, quartzite

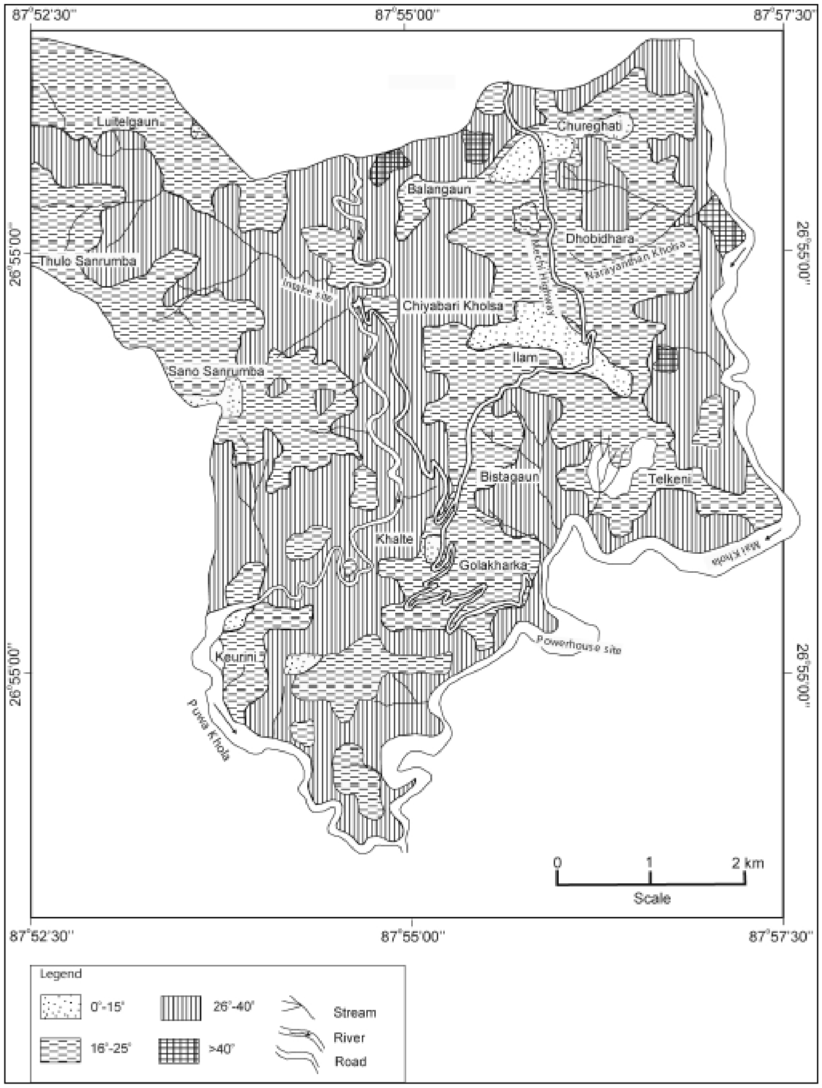

Figure 9*: Slope map of Ilam area.*

cliffs and active gullies, e.g. the Narayanthan Kholsa and Chiyabari Kholsa, represent the erosional landforms. River terraces, alluvial fans along the Puwa Khola and Mai Khola, talus cones of landslides are the main depositional landforms. The slope angles of the area are divided into the following four categories: 0°-15°, 16°-25°, 26°-40° and >40° (Figure 9). The Mai Khola is the trunk river and its major tributaries are the Puwa Khola and the Ghatte Khola. The Mai Khola and the Puwa Khola run due North-South and are more or less parallel to each other and join at Bhantar. Springs are frequently observed in fractured white quartzite. Sub-dendritic pattern is the common drainage pattern in the area.

Soils

Soils of the study area are classified according to their origin i.e. alluvial, colluvial and residual. Soil depth of the area is divided into shallow (1-3 m), medium (3-6 m) and thick (>6 m). Residual soils are extensively distributed on moderate to gentle slopes, along ridge and spurs i.e. Keurini, Golakharka

Bhanjyang, Bistagaon, Ilam Bazar, Godithumka, Chureghati, South-East of the Thulo Sanrumba (Figure 10). Colluvial soils are predominantly distributed in the study area. They are observed around Luitelgaon North-East of Thulo Sanrumba, Sano Sanrumba, Golakharka, Keurini etc. and are basically tallus deposits (Figure 10), which are shallow in depth at the upper slopes and thick in the foothills. Colluvial soils are composed of angular to sub-angular clasts of schist, gneiss and quartzite. Detail of engineering geological condition is shown in Figure 10.

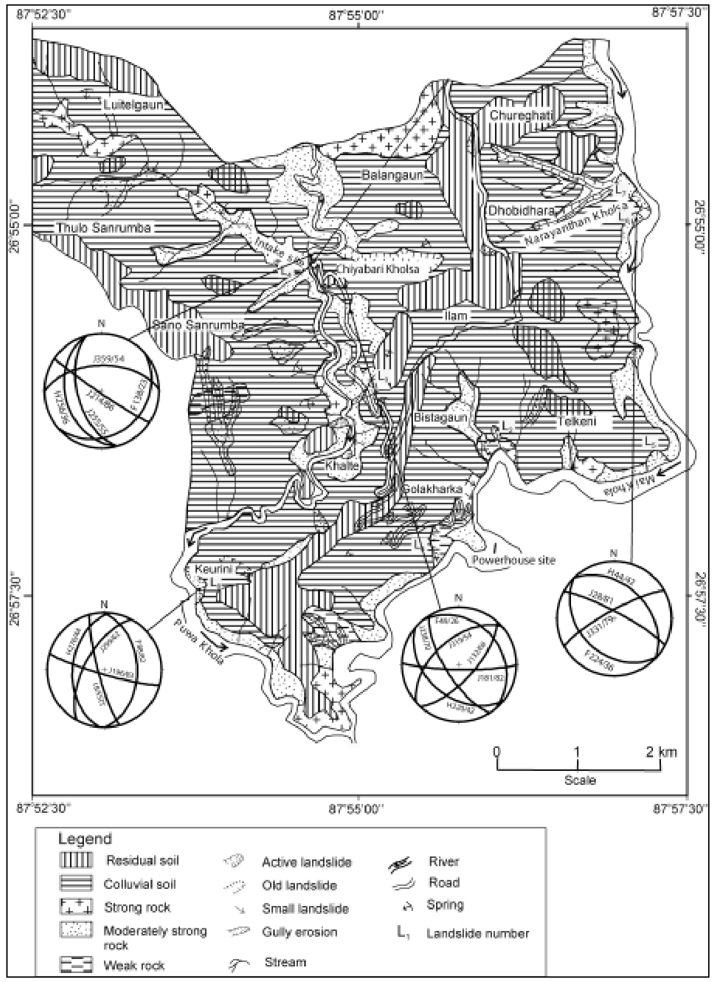

Figure 10: Engineering geological map of Ilam area.

Land use

Owing to the varied land structures, the land use pattern of the area is diverse. It is classified as forest, barren land, dry cultivated land, wet cultivated land, tea estate, shrub land, and settlement area. In the study area, conversion of the forest land to cultivable land is being accelerated due to population growth. About 62% land is cultivated. Dry cultivated land is extensively distributed in the eastern and western slopes whereas wet cultivated land is distributed in the central part of the study area. Other parts of the area and rocky terrain are covered by forest and shrub land.

Landslide

Landslides were studied using aerial photographs and topographic map along with detail field investigations, which revealed that about 6% of the total area, has been affected by landslides. The rainstorm of 1997 triggered off most of the slope failures. Mass wasting phenomena such as rock fall, rock topple, rotational slide, translational slide and gully

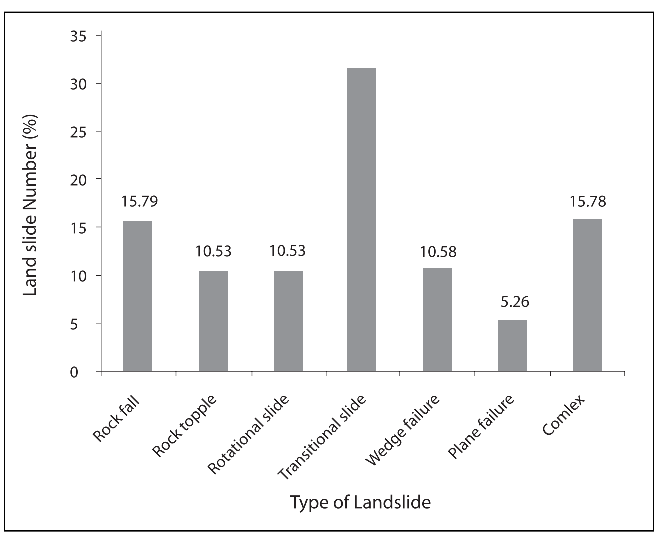

***Figure 11**: Distribution of different type of landslides in the study area.*

erosion are observed in the study area. Translational slides are more common in the area (Figure 11). In the study area, the population of wedge failure is the highest as compared to other failure types. Large landslides are especially common on south facing dip-slope but north-facing slope is more stable.

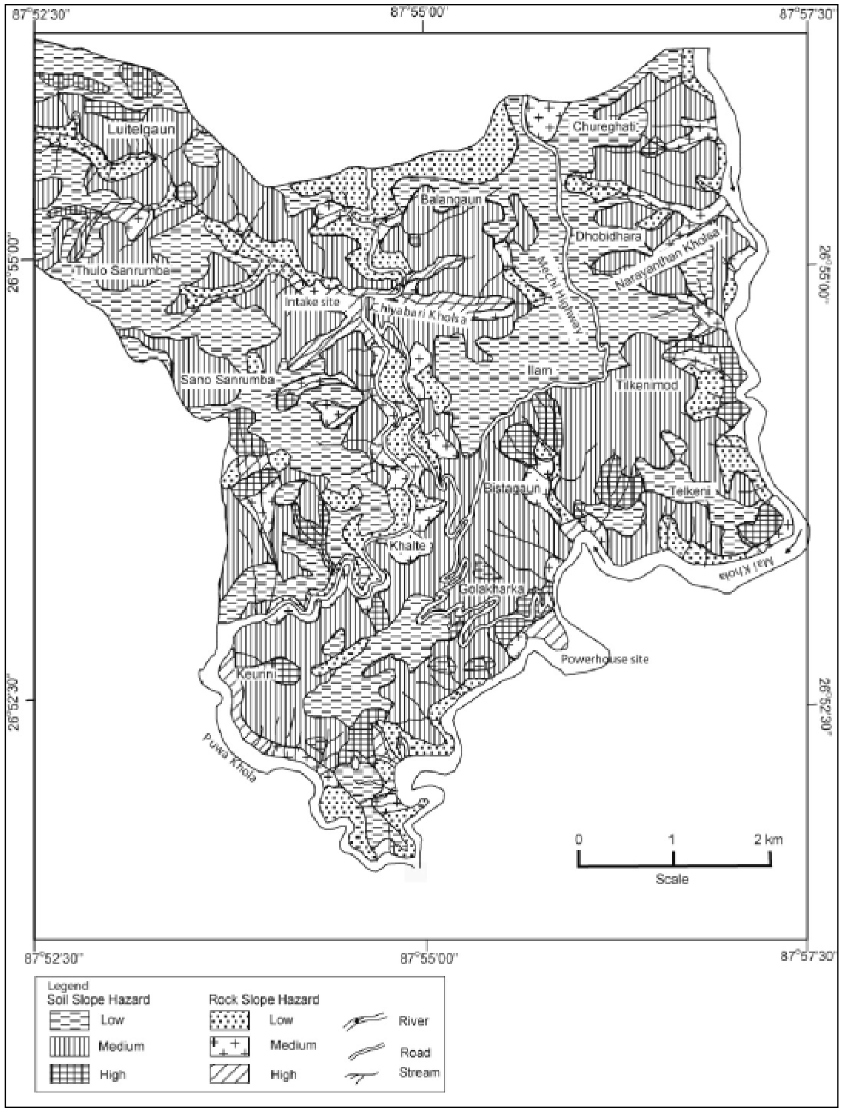

Figure 12 *: Relative landlside hazard map of Ilam area.*

Hazard assessment

The rock and soil hazard levels were classified into low (total rating: <40), medium (total rating: 40-65) and high (total rating: >65) depending upon the total rating values of different hazard components. Various levels of hazard and their location are shown in Figure 12. The most hazardous zones in the study area lie along the Puwa Khola, Mai Khola and in the active gullies. The main causative factors for landslide hazard in the study area are steep slope, rock discontinuity, land use pattern, soil depth and hydro-geological condition. High hazard zones are confined near Sanrumba, Luitelgaun, Keurini, Golakharka, Powerhouse site and Mahabhir north of Dhobidhara etc. Medium hazard zones are confined around Luitelgaun, Tilkenimod, Bistagaon. The remaining parts of the study area lie in low rock and soil hazards.

The obtained hazard map was then verified against the field condition to cross check its accuracy and found well corresponding. This has shown that the adopted methodology and components taken for the hazard mapping are able to reveal the relative hazard level. Superimposition method, therefore, may be the proper tool to delimit the landslide susceptible area in developing countries of south Asia, which share similar physiography and geology and where resources and technology for landslide hazard assessment, is limited.

Conclusion

Being mountainous country, every year, Nepal is suffering from problem of landslides and related phenomena causing a huge loss of economy, human lives affecting the mountain environment adversely. Therefore, an improved understanding of the natural processes, their impacts on natural hazards, and their relationships with human activities on the mountain slopes should be explored to reduce the effects of the natural hazards like landslides. The main hazard attributing factors in Nepalese Himalaya are steep slope, improper land use pattern, rock types and associated discontinuity, soil type and, soil depth. Slope angle between 260 and 400 found to be more susceptible for landslides. The conversion of forestland to arable land and shrub land has been accelerating hazard and also played central role in the development of slope instability and surface erosion. The superposition method (Deoja et al., 1991) of landslide hazard mapping is found to be a useful tool for delimiting the areas susceptible to sliding. This manual method may also be suitable for other mountainous countries of south Asia, where the advance methods are still inaccessible.

Recommendations

It is now clear that the number of landslide event and damage is constantly increasing in the recent years. Nepal, therefore, should come up with specific and feasible road map for the reduction of landslide and associated risks. In this context, following recommendations may be valuable to reduce risk of landslide in Nepal.

i) Establishment of specific institution for landslide study, assessment of landslide risk quantitatively and qualitatively at local and regional scales, monitoring, warning and preparation of data base that can be useful to make most essential action plan to reduce risk of landslide.
ii) Development activities (road, bridge, canal, tunnel etc) should be integrated with disaster management policy.
iii) Greater investment on research (slope instability and hazard zonation etc), education, training, and human resource development.
iv) Introduction of advance technology (e.g. remote sensing, GIS etc) to identify and monitor vulnerable slope.
v) Landslide hazard mapping by means of integrated approach both in regional and local scale should be given high priority.
vi) Coordination of financial and legal institution, insurance companies, disaster related organization to formulate disaster related insurance policy.
vii) Formation of institutional network of all organizations working on landslide and other disasters to share their knowledge and experience is recommended.
viii) Promotion of intensive public education, awareness and preparedness programs on landslide throughout vulnerable regions.

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Incipient Landslides in the Jhelum Valley, Pakistan Following the 8th October 2005 Earthquake

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Abstract

Extensive landsliding was a notable feature of the 8th October 2005 earthquake in India and Pakistan. The landslides ranged in size from small cut-slope failures to a rock avalanche with an estimated volume of about 80 million m^3 . In this paper we examine two key aspects of the landslides associated with the earthquake. First we attempt to estimate the number of fatalities associated with landsliding. We suggest that this is of the order of 26,500 people including 300 in India. As such this represents probably the third largest landslide disaster in recorded history. In the second part of the paper we examine the widespread occurrence of cracked slopes the Kashmir area of Pakistan. We attempt to explain this phenomenon by showing that prior to the earthquake the precipitation input was unusually low, resulting in slopes that were essentially dry at the time of the event. We suggest that these slopes are extremely vulnerable to reactivation during forthcoming wet seasons. As a result, there is a high level of threat to the population of Kashmir, and the landslides represent a significant potential source of problems during the rehabilitation phase in Pakistan.

Keywords: landslide, earthquake, Pakistan, cracking, deformation

Introduction

The 8th October 2005 earthquake in northern Pakistan and northwest India represents a disaster on a massive scale. At the time of writing the estimated number of fatalities is 87,350 in Pakistan, and 1,300 in India (Hussain et al . 2006), although some estimates put the total number of fatalities at approximately 100,000. Although not the largest in terms of energy release, the Kashmir earthquake represents the most devastating earthquake in South Asia in recorded history. As would be expected in a mountainous, tectonically-active area the earthquake triggered extensive landsliding. These landslides were responsible for a considerable proportion of the fatalities in both India and Pakistan.

As the reconstruction and rehabilitation of the earthquake a ected areas proceeds there has been increasing awareness in Pakistan of the threat posed by the landslides. In other mountainous areas a ected by earthquakes landslides have posed a threat to the local population and to infrastructure for years after the event. In this context, this paper provides a brief review of the landslides triggered by the earthquake. We then seek to examine the impact of the landslides expressed in terms of the number of fatalities, and to compare this with other large-scale landslide events. We show that this is one of the most deadly landslide triggering events in recorded history. Thereafter we focus on the ongoing issues associated with the extensive ground cracking initiated by the Kashmir earthquake.

Overall, in the paper we have attempted to show that this slope cracking phenomenon might be asso ciated with the hydrological status of the slopes at the time of the failure. Finally, we discuss the likely implications of this extensive cracking for the medium-term safety of the people in Kashmir.

The 8th October 2005 Earthquake

A full description of the geological aspects of the earthquake itself is given in Purnachandra Rao et al. (2006), and hence we only provide an outline overview here. The earthquake itself occurred on 8th October 2005 at 03:50:40 UTC (08:50:40 local time). The hypocentre of the earthquake was located at about 34.493 N, longitude 73.629° E and a focal depth of c. 20 km (Purnachandra Rao et al . 2006). The earthquake was succeeded by a long, intense aftersho ck sequence. The magnitude of the main event was M_L = 7.6 (USGS 2006), and of the largest aftershock was M_L= 6.3. The earthquake occurred as a result of an approximately 100 km long rupture of the previously-mapped Balakot-Bagh fault (now often termed the Muza arabad fault), which is a NNW-oriented thrust fault, dipping at an angle of 29° . The maximum displacement on the fault was about 5 m (Hussain et al. 2006).

The estimated intensity distribution is closely associated with proximity to the surface expression of the rupture zone. Within about 5 km of the fault trace the level of destruction is very high, but beyond this signs of damage are surprisingly minor, apart from the inevitable anomalous impacts of local effects. Unfortunately, the intensity of shaking cannot be empirically verified as there were no strong motion instruments recording in the Kashmir area at the time of the earthquake. However, eye-witness reports indicate that strong shaking lasted for approximately 40 seconds, with high vertical accelerations in particular.

The earthquake o ccurred south of the Main Boundary Thrust (MBT), at a location in which it makes an inverted "U-turn". This area is often referred to as the Hazara Kashmir Seismic Zone (HKSZ), representing a part of the Hazara Kashmir Syntaxis. This is an area in which a large earthquake has long been considered to be overdue, but unfortunately it is unlikely that the 8th October 2005 event has significantly reduced the probability of a very large event (Bilham et al. 2001), and indeed by redistributing the regional stress field it may have increased the likelihoo d of an forthcoming large earthquake.

The impact of the earthquake event was catastrophic. In addition to the fatalities outlined above, approximately 38,000 people were injured and in excess of 3.5 million were made homeless. In Kashmir many building performed poorly, with 780,000 structures being damaged beyond repair. In particular almost all Governmental structures were seriously damaged or collapsed. Combined with the timing of the earthquake this resulted in the tragic deaths of a very large number of children, estimated at over 19,000, primarily because of the collapse of Government schools (Hussainet al. 2006). It has been calculated by the World Bank that the costs of reconstruction and rehabilitation in Pakistani Kashmir will be in the order of 3.5 billion.

Seismically-induced landslides

Close to the fault rupture there was a high incidence of landslides triggered by the Kashmir earthquake. As would be expected, these include deep-seated failures; shallow, disrupted landslides; rockfalls; and cut-slope failures. The distribution of landslides appears to be very asymmetric, with most of the landslides being located on the hanging wall (north-eastern) side of the fault. The largest landslide o ccurred close to the town of Hattian Bala, approximately 3 km from the fault trace in a side valley of the Jhelum River valley system. Here a pre-existing landslide has been reactivated, resulting in about 80 million m^3 of material sliding over a total crown to to e distance of about 2 km. The resultant debris avalanche has blocked two valleys to a depth of over 100 m, and two lakes are currently forming on the upstream side of these obstructions. The landslide appears to be structurally-controlled, with the slide plane representing a plunging syncline. Thus, the failure is in e ect a complex dip-slope failure.

Essentially the amount of landsliding induced by the Kashmir earthquake is in many ways as would be expected according to previous studies (e.g. Keefer 1984). Perhaps the distribution in terms of the distance from the fault rupture on the footwall side of the fault is atypical, but may in reality map onto the distribution of uplift as implied by radar analysis of crustal deformation.

Fatalities

Estimating the death toll asso ciated with landslides in large seismic events is very problematic (see Petley et al. 2005, 2006 for example). In the chaos of the aftermath little attempt is made to di erentiate between injuries caused by building collapses and those associated with landslides. In addition, where large landslides have occurred, such as the Hattian landslide, it is rarely possible to recover the bodies of the victims and thus to estimate the true cost of the event. In this context, it is challenging to estimate the death toll associated with landslides in the Kashmir earthquake.

However, there are some potential sources of information. Interestingly, in India an accurate record was kept of the causes of fatalities, which showed that 300 of the 1300 deaths in Indian-controlled territory resulted from landslides. We have also tried to collect information on fatal landslides (Table 1). How-

***Table 1**: Known landslide fatalities in India and Pakistan resulting from the 8th October 2005 earthquake. Note that this represents only a fraction of the total landslide fatalities.*

Country	Location	Description	Fatalities
India	Srinagar-Muzaffarabad highway between Uri and Am an Setu	Indian Border Roads personnel buried in a bus by rockfalls	68
India	Eagle Picket, Tangdhar	Soldiers hit by a rockslide	12
India	Qazi Nag , Kalakote	Villagers hit and killed b y a rockslide	24
Pakistan	BandhiThanoliya	Destruction of complete village in mudslide	30
Pakistan	Hattianland slide	Villages of Lodhiabad, Bail, Cholian, Naina and Bat Shair all buried by m assive rockslide	600
Pakistan	Jabla	50% of the 196 buildings in the village buried by a landslide	17
Pakistan	Pahl, Jhelum Valley	Burial in landslides of every house in village of 600 people	250
Pakistan	Chalapani (10 km from Muzaffarabad)	Bus buried by rockfalls	13

ever, it is certain that this represents only a small fraction of the total number (for example, Table 1 lists 104 landslide fatalities in India out of a total of 300). For Pakistan, a better insight is probably given by the following statement (Bashir 2005):

> *"The severe October 8 earthquake rattled mountains where slopes were already destabilized by years of deforestation. O cials in the wildlife and forest department of Azad Jammu and Kashmir, (AJK) are of the view that an estimated 30% of the people who died in the magnitude 7.6 earthquake could have been saved if there had been fewer landslides...Some 100 villages fell from mountains, many of them into rivers, causing huge casualties... The AJK o cials said that the landslides also buried vehicles and killed many people on the spot. "It was unfortunate to see that all the debris and vehicles, including the bodies* of unfortunate souls that were blocking roads, had to be shoved into the river in order to reopen the road," they said."

Assuming that this Figure of 30% of fatalities o ccurring as a result of the direct or indirect impact of landslides, the death toll associated with the landslides would be about 26,200, plus 300 in India, i.e. 26,500 in total. If it is true that approximately 100 villages were destroyed totally by landslides then such an estimate might well be realistic. At present this is the best available estimate. Interestingly, a Figure of 30% of fatalities being the result of landslides agrees broadly with the figures for Indian Kashmir, where the 300 landslide fatalities represent 23% of the total.

Table 2 details the largest known landslide disasters, based upon Alexander (1989) and the International Landslide Centre database (see Petley et al. 2005 for details). Based upon this still-evolving list, the Kashmir earthquake may represent the fourth largest landslide-triggering event in terms of fatalities known to date. Clearly however further work is needed both to refine this list and to improve our understanding of the fatalities in the Kashmir earthquake. Certainly the Kashmir earthquake represents the largest fatality-inducing slope failure event in recorded history in South Asia.

***Table 2**: Recorded large-scale landslide events in terms of numbers of fatalities, compiled from Alexander (1989) and the ILC database (see Petley et al. 2005). Based on this dataset the Kashmir earthquake may be the fourth largest fatality-inducing landslide event in recorded history.*

Location	Date	Fatalities	Description
Gansu, China	16/12/1920	200,000	Earthquake triggered flow slides
Sichuan, China	10/06/1786	100,000	Collapse of landslide dam
Vargas, Venezuela	15/12/1995	30,000	Debris flows
N. Pakistan and India	08/08/2005	26,500	Earthquake triggered landslides and rockfalls
Nevado del Ruiz, Colombia	31/05/1970	22,000	Lahars
Nicaragua & Honduras	30/10/2005	19,600	Debris flows triggered by Hurricane Mitch
Nevados Huascaran, Peru	31/05/1970	18,000	Earthquake triggered landslide
Shimbara, Japan	1792	15,000	Debris avalanche and wave
TienShan, Tajikistan	1949	12,000	Earthquake triggered landslides
Mount Kelut, Indonesia	1919	5,000	Lahar
Huaraz, Peru	01/12/1941	5,000	Debris flow
Nevados Huascaran, Peru	10/01/1962	4,500	Earthquake triggered landslide
Gonaives, Haiti	19/09/2004	3,006	Mudflows triggered by Hurricane Jeanne
Cholima, Honduras	20/09/1973	2,800	Landslide
Sichuan, China	08/10/1933	2,500	Collapse of landslide dam
Vaiont, Italy	09/10/1963	2,100	Landslide into reservoir created wave
Fonds-Verettes, Haiti	24/05/2004	1,500	Mudflows
Guinsaugon, Leyte, Philippines	17/02/2006	1,450	Debris avalanche
Kure. Japan	1945	1,000	Mudflows and slides
Bihar, Bengal, India	01/10/1968	1,000	Landslide
Revantador, Ecuador	05/03/1987	1,000	Earthquake triggered landslides

Slope cracking in the Kashmir earthquake

Perhaps the most notable landslide aspect of the Kashmir earthquake is the very large extent of slope cracking in areas within 5 km of the fault. In most cases these appear to represent incipient landslides that have not developed to the point of full failure. As with the o ccurrence of landslides, the distribution of these features is limited to lo cations within about 5 km of the fault rupture, and in most (but not all) cases they are limited to slopes on the hanging wall block.

Two main types of cracked slope have been observed:

- **Cracked slopes at the top of bedrock slopes.** A small proportion of the cracked slopes (perhaps 20–25%) o ccur at the top of ro ck cli s formed from in situ bedro ck, primarily the Precambrian materials. Here, multiple arrays of arcuate cracks are observed behind the crown of the cli (Figure 1). In many cases these cracks define blocks with a down slope length of 50 m or more, and a cross slope extension of over 100 m. The lateral shears of the defined slide blocks often follow existing topographic features (Figure 1), such as gullies. In many cases the crack systems define a complete block. The cracks are often up to 1 m in width, with steps of 50 cm or more. In some cases the crack arrays even traverse reverse slopes (Figure 2).

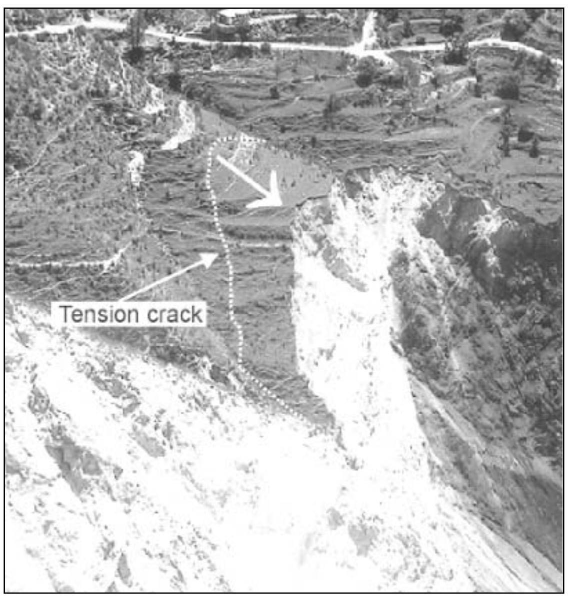

***Figure 1**: A cracked slope in unweathered Precambrian dolomite at Mukree. Here a block about 50 m in length is sliding forward. At the time of the photograph the tension crack was about 50 cm in width.*

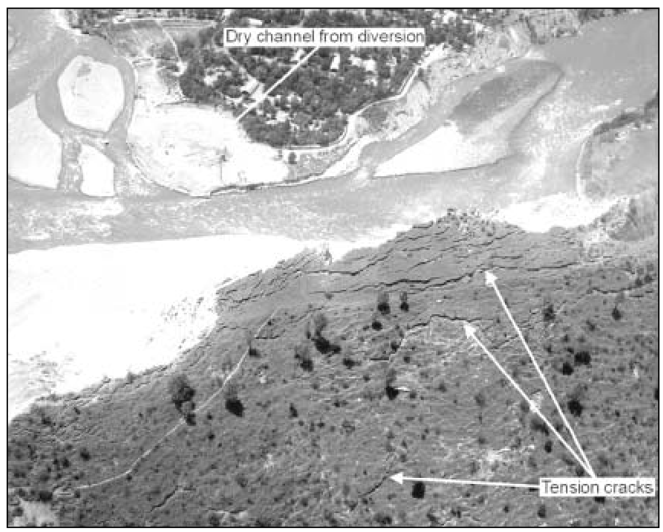

***Figure 2**: A cracked slope in unweathered Precambrian dolomite above the Nisar camp upstream on the Neelum river from Muza arabad. The cracks daylight on a reverse slope at the top of a 200 m cliff. A large failure here during the earthquake blo cked the river, causing the labeled change in the drainage.*

- **Cracked slopes in colluvium.** The majority of the cracked slopes appear to represent partially developed landslides in colluvial materials (Figure 3). Here, multiple arrays of large, arcuate cracks are seen traversing slopes with gradients in the range 20–45 (Figure 4). In many cases these define completely potential landslide blo cks, some as large as 200 m in length and 500 m in width, with fully developed lateral shear systems. Extension across the cracks is in places as much as 2 m horizontally and 1.5 m vertically. In many locations graben structures appear to have developed in the crown area of the incipient landslides, and there is clear evidence of changes to the slope hydrogeology, with large, well-established springs having disappeared at the time of the earthquake. There are however almost no reports of new areas of seepage across the a ected hillslopes.

Figure 3: *A cracked slope in colluvium in the Jhelum River valley. The annotated image shows the locations of the main cracks. Note the clearly defined main block, complete with fully developed lateral shears, and less well developed slope failures above and on the margins of the main slide. Crack widths at this lo cation exceed 1 m.*

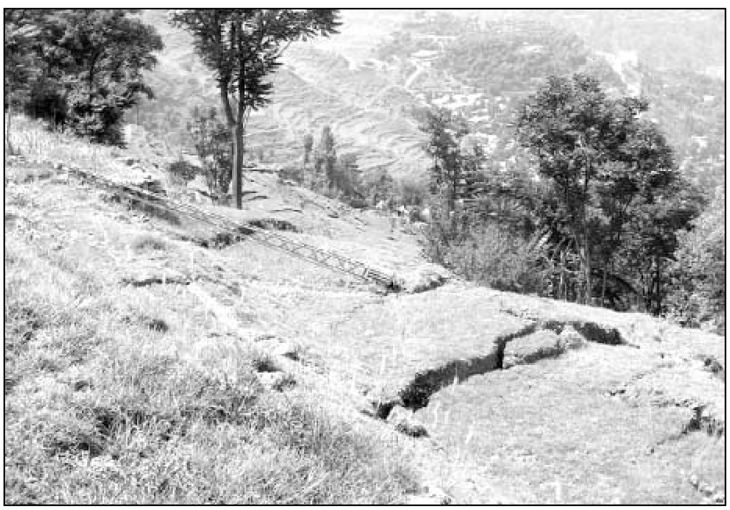

Figure 4: *. Ground cracks at Botha, on the colluvium slopes above Muza arabad. At this location there are multiple arrays of cracks extending upslope for over 200 m, and across the slope for over 500 m. The orientation of the cracks varies according to local topographic controls.*

This extensive occurrence of slope cracking is unusual for seismically-triggered landsliding. In other areas slope cracks have been observed, but generally speaking they are not as extensive as in this case. It appears that many slopes have effectively failed during the ground shaking, but have not been able to transition into full runout landslides, even on quite steep slopes. The slope gradients and lithologies involved are not exceptional in any way, suggesting that this behaviour is not the result of a material control on movement. The probable explanation for this phenomena lies with the precipitation that had been deposited in the area in the perio d preceding the earthquake. Figure 5 shows the rainfall record for the grid square 73–74° E 34–35°N, in which the Muza arabad area lies. These data have been obtained from the monthly monitoring data for precipitation produced by the Global Precipitation Climatology Centre (GPCC) (see Rudolf et al. 2005). This is based upon rain gauge records for 7000 surface stations. The gauge error in this area is estimated to be ±5%, and in general the GPCC dataset consistently underestimates slightly the true level of precipitation (Rudolf et al. 2005). These data suggest that in the months leading up to the earthquake the precipitation level was anomalously low. In fact, in the period between March and September 2005 the recorded precipitation in this grid square was just 54% of its long term mean. In the Kashmir area, 44% of an-

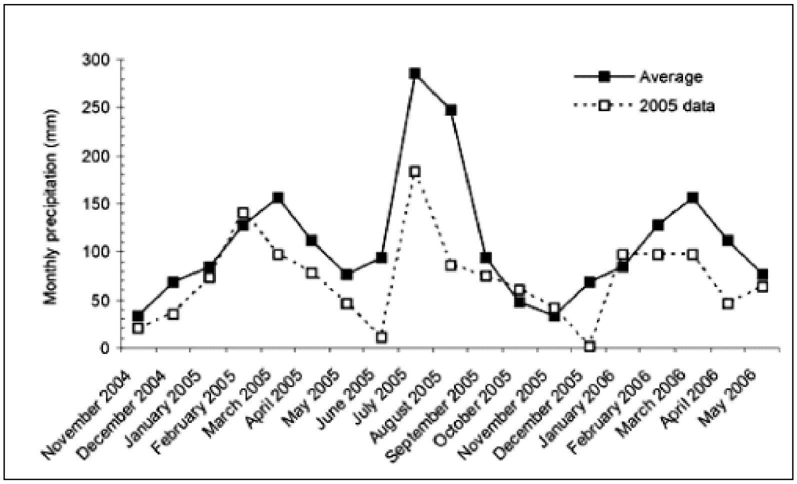

Figure 5: *Rainfall record for the grid square 73-74° E 34-35° N (data from GPCC — see Rudolf et al. 2005) for the period November 2004 to May 2006. It is clear that for most of the year before the earthquake in October 2005 the rainfall level was significantly below average. In particular there was a very low level of monsoon rainfall. Interestingly, the perio d since the earthquake is also marked by low level of precipitation.*

nual precipitation occurs as a result of the SW Monsoon between July and September. In 2005 the precipitation during this monsoon period was 55% of the long term mean. Thus, prior to the earthquake the Kashmir region effectively suffered the effects of a severe drought. It is likely that as a result groundwater levels were unusually low, and thus that the slopes were in effect dry. Unfortunately no piezometer data are available for the Kashmir area to verify this observation.

Hence, it seems probable that the extensive slope cracking observed in the earthquake a ected area was the result of landslides that were triggered by the earthquake, but could not transition to full failure due to the lack of groundwater. Interestingly, at the time of writing (July 2006) these slopes had remained effectively stable. However, the period since the earthquake was also marked by warm temperatures and, more importantly, dry conditions. In the period October 2005–May 2006 only 72% of the long term average precipitation was deposited. Thus, at the time of writing the slopes remain unseasonally dry.

Long term implications of the cracked slopes

In other steep mountain chains that have been subject to large seismic events the density of landsliding increases dramatically in the rainy periods immediately following the earthquake. For example, Lin et al. (2006a) reported that the area of landslides in the Choushui River catchment in Taiwan increased from 35.52 km^2 before the 1999 Chi-Chi earthquake to 57.37 km^2 in early 2000 after the seismic event. However, subsequent rainfall events increased the area of landsliding dramatically, reaching 148.81 km^2 by the middle of August 2001. Thus, whilst the earthquake increased the spatial extent of landslides by about 61%, the area had increased had increased by 260% above the post-earthquake level within 18 months, as a result of the effects of two wet seasons. Chen and Petley (2005) and Lin et al. (2006b) provided similar evidence of increases in the occurrence of landslides in other Taiwan catchments in the post-seismic phase. Interestingly though the increase in landslide area was mostly asso ciated with increases in surface area of existing landslides, even during the seismic event. Thus, during the earthquake the area of new (i.e. first time) landslides in the Choushui catchment was only 7.47 km^2 . The area of new landslides in triggered by the subsequent rainfall events was only 26.74 km^2 out of an increase in surface area of 91.44 km^2 (Lin et al. 2006a).

It seems very likely that in the next few years the area of landsliding in the Kashmir earthquake zone will also undergo a large increase as a result of the effects of rainfall. As many of the cracked slopes are probably at residual strength, it is likely that as the groundwater level rises large numbers of slope failures will o ccur. At the time of writing, which represents the first week of the 2006 monsoon, there is some evidence that this is beginning to occur, with newspaper reports that 13 people had been killed by a landslide on the outskirts of Muza arabad in an area of extensively cracked slopes, and widespread disruption to vehicular tra c from landslide and ro ckfall activity, with one event having killed a road-user. It seems highly likely that this situation will deteriorate in the coming months and years.

Discussion

In this paper we have attempted to examine two aspects of the Kashmir earthquake. First, we have attempted to examine the event in terms of the numbers of lives lost, and in particular to estimate the likely number of fatalities. It is clear that the earthquake event represents one of the largest fatality-inducing events in history, although much more work is needed to gain a reliable estimate of the number of fatalities. We then fo cus on the future evolution of the Kashmir area, suggesting that there is a high likelihood of many more landslides, and thus a substantial increase in loss of life. There is a need to mitigate this threat through hazard assessment. However, the presence of the cracked slopes also raises some fundamental questions about one of the key techniques for assessing the hazards asso ciated with earthquake-triggered landslides — the Newmark Displacement method. This approach, proposed by Newmark (1965), is based upon the application of a simple model of a landslide, in which the system is considered to act as a block on an inclined plane. The Newmark's method calculates the cumulative displacement of the blo ck resulting from an acceleration time history for the earthquake. Movement of the block is assumed to occur when the calculated sum of the static and dynamic driving forces exceed the shear resistance of the block. Thus, permanent deformation occurs when induced accelerations exceed some critical acceleration (see Miles and Ho 1999 for example). It is assumed that failure of the landslide has occurred when some critical displacement is reached, but this distance is in general very po orly defined (Murphy et al. 2002 for example). Indeed, in many cases it appears to be entirely arbitrary. For example, failures occurring in rocky slopes (i.e. disrupted falls and slides) are often assumed to have a critical displacement of 5 cm (Romeo, 2000 for example). On the other hand a critical displacement of 10 cm is often assumed for ows and slides occurring in cohesive soils (Jibson and Keefer, 1993 for example). However, clearly the slides observed in Kashmir, which constitute a combination of ro ck slopes and cohesive materials, have undergone much greater displacements than this and yet have still to fail. Indeed in some cases the tension crack systems indicate a displacement of in the order of several metres. Therefore, the small critical displacements as are generally used in Newmark analyses appear to be unsupported by field evidence. It is perhaps more logical to work on the basis of a critical strain at failure, rather than a critical displacement.

Conclusions

The key conclusions arising from this work are as follows:

1. The Kashmir earthquake represents a remarkable event in terms of landslide fatalities, probably repre- senting one of the largest landslide disasters in recorded history;

2. The occurrence of landslides was probably lower than might have otherwise been expected due to the low rainfall totals in the year preceding the earthquake;
3. The presence of extensive slope cracks in areas on the hanging wall blo ck indicates that there are likely to be many landslides in the next few years. Mostly these are likely to be associated with monsoon rainfall;
4. As such there remains a very high threat to the population of Kashmir and Nothwest Frontier Province in the forthcoming years;
5. The large displacements on these crack systems suggest that the critical displacements used in Newmark displacement analyses are probably incorrect.

Acknowledgements

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Overview and Advancement in Landslide Risk Management in Sri Lanka

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Abstract

The following paper discusses Sri Lanka's natural disasters in concise form, with special reference to the landslide disaster, the extent and its distribution, causative factors, mitigatory processes, early warning, including currently employed and proposed measures and the legal status that affects the actual implementation of both pre and post landslide disaster events.

Sri Lanka, the pearl of the Indian Ocean, and known for her scenic beauty, is endowed with some of world's most beautiful gems an quality teas producing about a quarter of tea requirement the tea of the world. It is somewhat strategically located between northern latitudes of 5°511 and 9°511 and eastern longitudes of 79°401 and 81°551 approximately 24 km to the southeast of India. Sri Lanka occupies an area of nearly 65,000 sq.km., stretching to 435 km from north to south and 224 km from east to west.

The country as a whole has undergone extensive land degradation due to a host of reasons, inter alia, factors such as soil erosion and denudational processes are predominant. These factors, together with the common triggering factor - intensive precipitation - due to the south west and north east monsoonal and inter monsoonal rains, exacerbate the incidence of landslides in 10 districts occupying the central hilly region and the abutting sloping terrain of the south west of the country. The net result of heavy rain on the already strained terrain due to erosive and denudation processes, in Sri Lanka's case, causes concern due to the lack of land availability. In this context, the absence of a legal framework, which enhances the mitigatory process, also affects both pre and post disaster situations. Although legislative enactments have been under discussion, actual implementation appears to be lagging behind for obvious reasons of pressure on land availability together with financial constraints and Sri Lanka's instance is no exception to many third world countries.

Introduction

Sri Lanka, is located in the Indian Ocean between northern latitudes of 5°511 and 9°511 and eastern longitudes of 79°401 and 81°551 approximately 24 km to the southeast of India. Sri Lanka occupies an area of nearly 65,000 sq km stretching to 435 km from North to South and 224 km from West and East.

Democratic Socialist Republic of Sri Lanka is a free, independent and sovereign nation. Parliament has a single chamber with 225 members. Members are elected by the nation. A system of provincial administration through Provincial Councils was introduced in 1988. Legislative power is exercised by parliament, elected by universal franchise on a proportional representation.

The climate of Sri Lanka varies from semi-arid to mild temperature. This variation due to central highland region being surrounded by an extensive low land area is influenced by two monsoonal and inter-monsoonal periods. Annual rainfall varies from 2500 mm to over 5000 mm in the south-west of the island, while in the north-west and south-east, rainfall averages less than 1250 mm annually. Mean annual temperature is 27° C in the lowlands of Sri Lanka and in the central highland with an altitude of up to 400 meter; the mean temperature is 15° C.

Total population of the country is nearly 19 million and the literacy rate is around is 91.8%. The people of Sri Lanka belong to one of three ethnic and social groups, namely Sinhala, Tamil and Muslim. The largest group, speaks Sinhala while English is widely spoken and understood. Sri Lanka is a land of religious tolerance with 70% of Buddhist, 16% of Hindu, 7% of Christians and 7% of Islam living together.

Sri Lanka's economy was dominated by agriculture over the years. But with market liberalization, the situation changed and the manufacturing sector gradually emerged. At present, the value addition to the Gross Domestic Product (GDP) of the manufacturing sector is higher than the agriculture.

Landform and Geology

The island is made of three well-recognized elevation levels termed as peneplains. Lowest peneplain consists of terrain between the sea level and the 100-meter elevation. Middle peneplain ranges from 100 to 1000 meter in elevation consisting of hill ranges dissected by numerous drainage systems. Highest peneplain comprises central highlands between 1000 meter and 2500 meter elevation.

Sri Lanka forms the southern continuation of Indian Precambrian shield and crystalline metamorphic rocks underlie over 90 percent of the country. The rest consists of sedimentary rocks of predominately Miocene age and some of the Jurassic age mainly confined to the northwestern sector of the country. The Precambrian rocks of Sri Lanka are made of three major groups, namely the highland series, the Vijayan Complex and the Southwestern group. The highland series occupies mainly the central part. Consisting of pyroxene granulites, facies rocks made of garnet sillimentite gneisses, graphite schist, charnockites, quartzites and marbles. The vijayan complex rocks, consists of mainly granitic gneisses, hornblende biotlite gneisses and migmatites formed under amphibolites facies and are mainly confined to the eastern sector. The southwestern group consists of cordierite granulite facies rocks made of cordierite gneisses calc granulites and metasediments.

Land Degradation and Forest Cover

Land erosion has been increasingly prominent due to ill soil conservation practices such as rampart slope cuttings and forest clearings for human settlements, infrastructure development and gem and sand mining, chena cultivation etc. Landslides add further to the effects of erosion, especially in the cultivated slopes of the hill country. Sri Lanka's forest cover now occupies less than world accepted minimum requirement for a country.

Extent of the Landslide Problem and Causative Factors

In Sri Lanka, most of the landslides, rock and cutting failures occur in the central highland of the country. The central region of Sri Lanka is hilly and mountainous with highly fractured and folded basement rock overlain by residual soil and colluvium. It is about 20% of the total land area and is occupied by 30% of the total population of the country. Landslides, slope failures and rock falls and reactivation of them is a frequent phenomenon in these areas causing severe damages to life and property. Therefore, occurrence of frequent Landslides and slope failures could be considered as the most significant natural disaster in Sri Lanka. They are likely to have a greater economic impact in the urban and semi urban environment when there is a possibility of damage and losses to investments on various development projects, infrastructure facilities and more important to lives. The total extents of loss of forest cover, wild life and damage to the eco-system by landslides cannot be estimated and will probably remain unknown.

An area of nearly 20,000 sq.km of area covering the districts of Badulla, Nuwara Eliya, Ratnapura, Kegalle, Kalutara, Kandy, Matale, Matara, Galle and Hambantota is prone to landsiding. The appended map depicts the extent of the landslide hazard potential in Sri Lanka (Figure 1). Each spot on the map represents a landslide event involving a death and/or a human settlement or an infrastructural facility such as railway line, road, house or bridge etc.

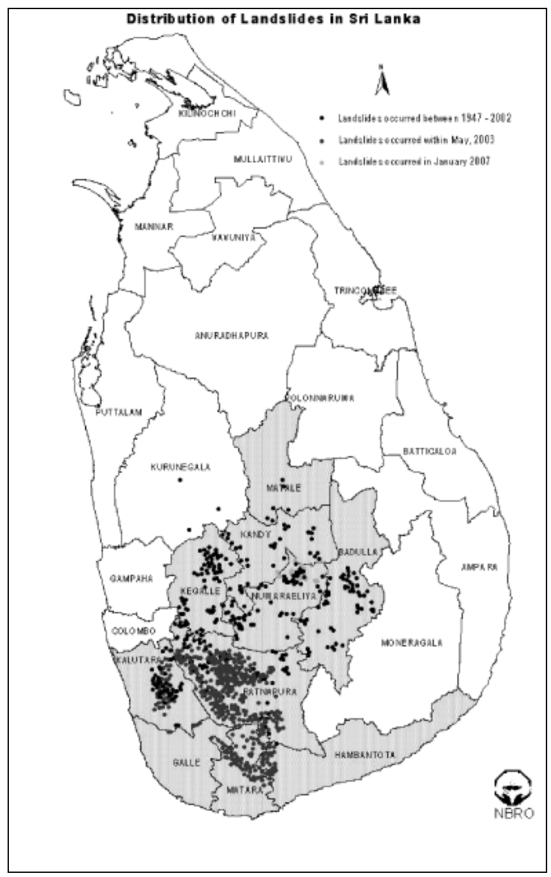


Figure 1: Past landslide locations and the landslide prone districts of Sri Lanka

The incidence of landslides and the frequency of its occurrence are growing by the year. The present landslide density is estimated to be in the order of 1-2 landslides per sq.km, within the hilly landslide prone districts of the country and where slope degradation processes are at an advanced stage, one landslide is reportedly being added to every 6 sq km every year.

In Sri Lanka, the major triggering factor of landslides has been intensive heavy rains. However, changes resulting from undue human intervention such as bad land use and cropping practices, settlements in unstable areas, changes in and blocking of the normal drainage courses, non-engineered practices in development works have caused a phenomenal increase in the incidence of landslides on hilly areas. This is clearly exemplified by the fact that landslides observed in the initial mapping stages in 1990 were found to be mainly due to natural causes whereas those which occurred after the recent flashfloods in May 2003 and January 2007were mainly due to improper land use practices e.g. cutting of hill slopes for development works.

As a result of the historic heavy precipitation in May 2003, 191 persons were killed, 3000 families were severely affected by landslides while their dwellings were destroyed. Same results encountered due to heavy precipitation in January 2007. More than 45 persons were killed, nearly 5000 families were severely affected Consequent to these rains, a total economic loss of thousand millions resulted due to landslides and floods.

3. Landslide Hazard Zonation Mapping

Landslide Hazard Zonation Mapping Project (LHMP) culminated as an aftermath to the Government Cabinet Paper 116 of 16th June 1986. Phase I was carried out between 1990 and 1995 with technical and financial assistance of UNDP/UNCHS and thereafter funded by the Government of Sri Lanka as indicated below in Table 1.

***Table 1**: Landslide hazard maping Program*

Phase	Period		Districts covered	Area covered/Projected area (Sq.km.)
	From	To		
I	1990	1995	Badulla & Nuwara Eliya	1480
II	1996	1999	Kegalle & Ratnapura	1480
III	2000	2004	Kandy & Matale	1400
IV	2005	2007	Kalutara	600
V	2007	2011	Galle,Matara,Hambantota	1200
Total				**6160**

The above forms part of the normal LHMP mapping program of NBRO and is carried out at the conventional scale of 1:10,000, based on the topographic maps of the Survey Department, Sri Lanka.

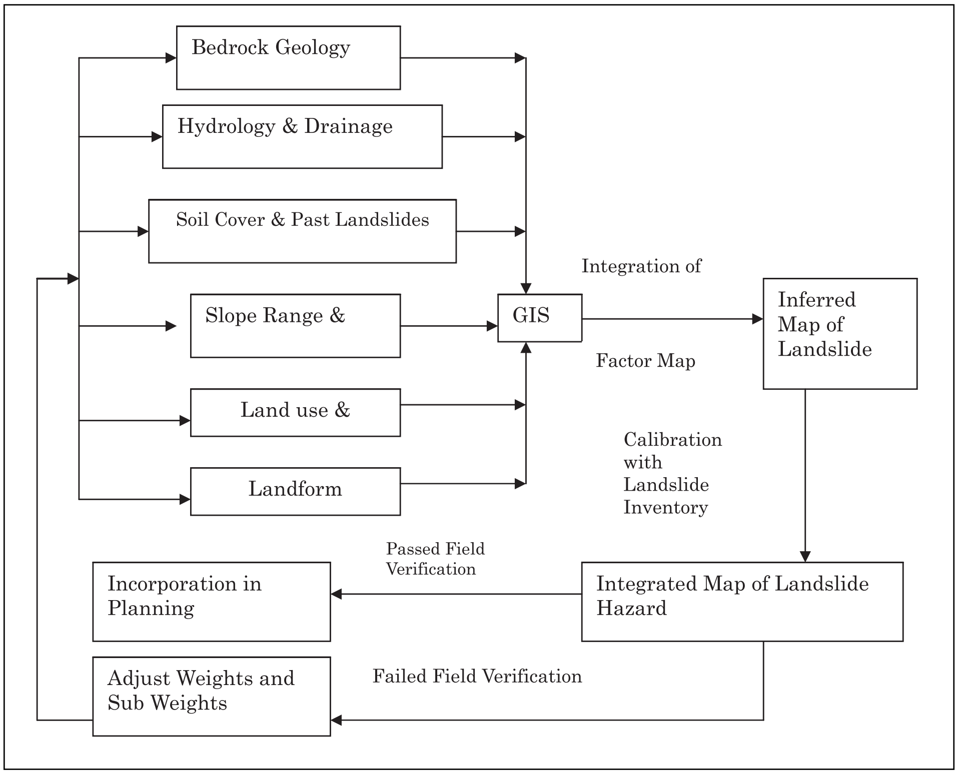
Consequent to record flash floods in May 2003, encompassing 5 districts and causing a major catastrophe, 3189 severely affected families had to be evacuated and a total of 191 deaths resulted. As an aftermath to the above holocaust, Cabinet approval was obtained for Cabinet Paper 03/1372/111/061 dated 17.07.2003, by which NBRO was requested to include an additional 2400 sq.km. for landslide hazard zonation mapping covering 3 new southern districts namely, Matara, Galle and Hambantota.

Method used for Hazard Mapping

Landslide Hazard Zonation maps have been compiled starting with the following categories of "state-of-nature" maps. The basic data are gathered from field surveys as well as from desk studies. A set of “derived maps” is then deduced from these maps using an appropriate scoring (point) system, which are later analyzed by the use of a computer program. An overview of the methodology of the process is given in the appended Flow Chart. No. 1

1. Slope category
2. Bedrock Geology and Structure
3. Past landslides and overburden deposit
4. Landform

5. Land use and management
6. Human settlements and infrastructure
7. Hydrology



***Flow Chart No. 1** : Landslide Hazard Mapping Methodology*

Derived Maps of Geology

Each of these maps constitutes a basic element of landslide hazard mapping. It aims at qualifying geological factors that affect the stability of slopes.

The following sectors have been considered in the preparation of this map.

- The geological map unit
- The steepness of the dip of the bedrock foliation
- The orientation of the topographic slope with respect to the attitude of the bedrock foliation
- The presence of faults or lineaments

Landslide Hazard Zonation Map

Landslide Hazard Zonation Map is the ultimate product of the landslide hazard zonation mapping process. Production of this map is done by integrating the effect of all the categories of maps mentioned above with the use of GIS Software (eg. PC ARC/INFO) Cumulative attribute values associated with the hazard map are categorized into four different ranges depending on the degree of the hazard. An overview of the methodology of the process is given in the following diagram.

***Table 2**: Criterion for Landslide Hazard Zonation*

Overall Hazard Rating (R)	Hazard Zone	Description
R< = 40	I	Safe Slopes
40<R<=55	II	Landslides likely to occur
55<R<=70	III	Modest level of landslide hazard exists.
70<R	IV	Landslides are expected.

These hazard zonation maps are presently utilized by several institutions including the following important state and parasitical institutions. Among them, the National Physical Planning Department (NPPD) the key Government department responsible for the macro-planning process of the country has already integrated the use of the LHMP maps as mandatory in their planning strategy.

(i) National Policy Planning Department (NPPD)
(ii) Central Environmental Authority (CEA)
(iii) Road Development Authority (RDA)
(iv) Urban Development Authority (UDA)
(v) National Housing Development Authority (NHDA)
(vi) Disaster Management Center (DMC)
(vii) Local Authorities (LA)
(viii) Forest Department

Apart from carrying out research studies on landslides, the inalienable responsibility to provide advisory services on vulnerability to landslides and slope cutting failures specially to the state sector and the public in general cannot be eluded by NBRO. Concurrently, NBRO is also engaged in landslide awareness dissemination from the grassroots level to policy makers to include a gamut of stakeholders through special Awareness Programs held in the various vulnerable districts. These have been received by the communities with great enthusiasm. NBRO is also continuously involved in detailed geological and geotechnical investigations of sites needing specific attention, at the request of various applicants including the local authorities.

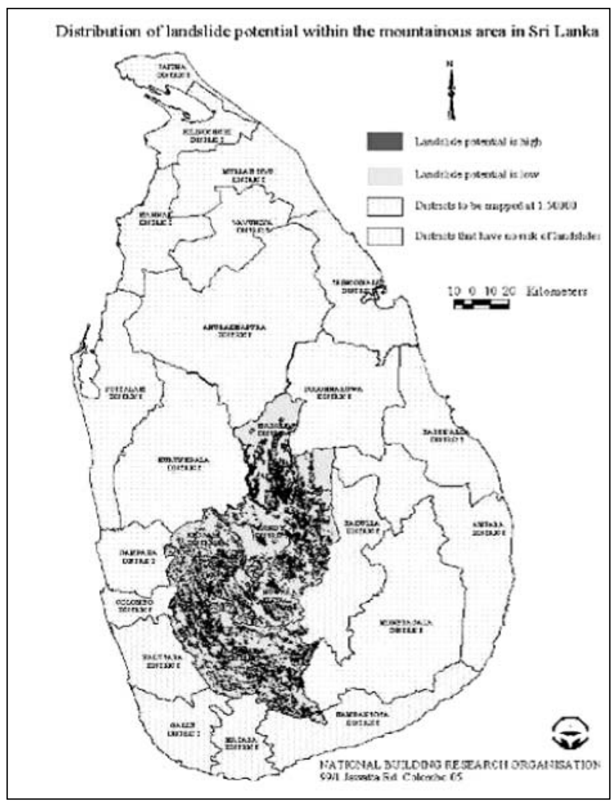


***Figure 2** : Partially Completed landslide zonation map for Sri Lanka.*

Mitigation Strategy

In spite of activities such as hazard mapping, revision of land use maps and preparation of development plans, a proper national level mitigation strategy does not function as yet.

In the early 1940, landslide investigation work was one of the functions of the Department of Mineralogy/Geological Survey Department. Initiatives of far reaching consequences, however, stemmed from the Government of Sri Lanka's Cabinet Paper 116 of 16th June 1986. NBRO report titles "Landslide Hazards in Sri Lanka" provided the basis for the above Cabinet paper. By then, it was clearly understood that as many as 7 districts namely Badulla, Nuwara Eliya, Keglle, Ratnapura, Kandy, Kalutara and Matale were landslide prone.

NBRO was directed by the Government to undertake mapping of landslide hazards, to start with, in the two of the most affected districts - Badulla and Nuwara Eliya, on an urgent basis. The Government of Sri Lanka, the UNDP and the UNCHS jointly worked out on a project to be implemented by NBRO, reflecting on the causes of environmental degradation, with particular reference to landslides, (Project SRL/84/036). The study pinpointed hazardous areas and yielded recommendations on remedial measures including guidelines for improved land use management.

Deeply concerned with the menace of landslides, the Government of Sri Lanka sought UNDP/UNCHS assistance, which eventually culminated in the signing of a Project on Landslide Hazard Mapping (SRL/89/001) on 15th December 1989 between UNDP, UNCHS and the Government of Sri Lanka. The project which was funded by the UNDP to the tune of US$ 1.8 million plus, and backed by the Government inputs of about Rs. 34 million became operational in August 1990. It was poised to deliver the targeted outputs by July 1995. The Government's National Environmental Action Plan came in 1990 as a yet another landmark. The Plan laid special emphasis on the need for extension of the ongoing Landslide Hazard Mapping Project to the Kegalle District.

The Government pressed on with its initiative during 1990-1991, which culminated in the report of the Inter Ministerial Coordination Committee on Disaster Preparedness and Management, compiled by the Central Environmental Authority in April 1990. It devoted an exclusive chapter to Landslides. The most significant development has however been the release of the draft National Disaster Management Plan of January 1992, authored jointly by the Ministry of Reconstruction, Rehabilitation and Social Welfare and the Ministry of Policy Planning and Implementation. It covers disasters due to landslides adequately.

The Government of Sri Lanka is currently in the process of finalizing the legal provisions for Disaster Management through the "Disaster Management Counter Measures Bill" referred to Parliament for approval. The Bill envisages setting up of the National Disaster Management Council that will be the apex legal body for the formulation of work plans and programmes. The finalized plan for disaster management will spell out polices for and an improved institutional arrangement from national to village level.

Consequent to a memorandum submitted by NBRO to the Government after the flashfloods and landslides in May 2003, approval was granted for Cabinet Paper no. 03/1372/111/061 dated 17.07.2003 on "Development of Risk Free Sustainable Human Settlement by Implementing Recommendations of the National Building Research Organisation (NBRO) through the Development Planning Process".

Mitigation Intervention

Disaster Mitigation is integrated in the EIA process. In the screening process, scoping meetings for determining the TOR and in the EIA report, this aspect is integrated. This is a requirement in landslide prone areas and it encompasses mini hydro-power projects, quarries and large scale housing schemes. Presently Natural Resources Management Centre (NRMC) of Sri Lanka by the enforcement of the Soil Conservation Act, inhibits soil erosion, thereby playing a mitigatory role against many natural disasters as well as environmental pollution.

Among tangible examples of structural intervention in risk mitigation works in the past, a major milestone is the detailed study of the landslide near Watawala railway station structural work connected with NBRO recommendation for lowering of ground water table was carried out by an Australian company in 1992/1993 and the railway line has been stabilized since then..

Other intervention includes landslides on trunk roads leading to Beragala, Pussellawa, Koslanda, where Sri Lankan Road Development Authority executed road repairs creating the necessary surface drainage network and the lowering of the ground water table conducive to the stability of roads. Also, the National Housing Development Authority now designs their housing schemes on hill slops to suit the terrain conditions by including retaining structures and appropriate drainage networks. Among some community-based mitigation works carried in landslide risk areas are sites in Nawalapitiya, Kandy District, which include drainage network development, forestation and excavation of trenches.

A systematic incentive scheme to discourage dwellers or cultivators on unstable slops has not existed until in 2003, the Government made a reasonable attempt to compensate the hillside dwellers to abandon the affected slopes and also to be rehabilitated on suitable land. Although Insurance scheme do exist to cover certain disasters. Natural disasters are not covered by insurance coverage, but some initiatives have been made to persuade Insurance companies to play a role, but with little avail. A difficulty to encourage dwellers on unstable slopes to abandon them, especially those dogmatic and the conventional hillside cultivators, still exist and unless very large sums can be disbursed, little can be expected in that direction for the time being.

Early warning in landslide prone areas of Sri Lanka

Almost all Sri Lankan landslides that have been investigated to date are known to be rain induced. Therefore development of a early warning system should be always interpreted with the landslide events in terms of the rainfall patterns, immediately preceding the slide event. Same time it was considered two type of situations when giving early warnings

a. Early warning against possible re-activation of old landslides or development of new landslides in the areas identified as landslide prone areas
b. Early warning against occurrences of fresh landslides in the areas without any significant of pervious landslide history or without any early symptoms.

NBRO's study on the landslides and the preparation of landslide hazard zonation maps were given the initial solution to identify the both type of above areas. After critically evaluation of these two areas with the help of the zonation maps and adding the another two categories on soil parameters and rainfall intercity,NBRO has already developed and practice an early warning system through out the landslide prone areas of Sri Lanka

***Table 3**: Early warning steps and threshold limits for landslide warnings in Sri Lankan Landslide*

Type	Threshold limits	Warning type
Warning Part 1 (Alert)	75 mm rainfall for 24 hours	alert for Landslides
Warning Part 2 (Warning)	100 mm rainfall for 24 hours	Get ready to evacuation under short notice
Warning Part 3 (Evacuation)-	150 mm rainfall for 24 hours Or 75mm rainfall per hour	Evacuation

Even through the values of rainfall in most parts of the landslide prone districts were already identified, to increase the effectiveness and the best results, community awareness and the facilities to measure the rainfall especially in the village level should be increased Therefore, proper awareness of critical rainfall values and quantitative measuring of rainfall are beneficial for landslide forecasting specially in village level. By providing simple rain gauges with necessary training, even the village community was introduced through the JICA and UNDP granted special projected introduced to the selected vulnerable villages located in Kalutara and Ratnapura Districts.

Capacity Building and Experience Sharing

NBRO organized the first National symposium on Landslides as an activity under Landslide Hazard Mapping Project in 1994 and it provided a forum for all participating institutions and professionals to

Landslide at Beragala - 2008.

Landslide at Munwatta, Walapane – 2007.

discuss the problems associated with mountain development for the first time. Subsequently NBRO and CHPB organized a workshop on the Role of R & D Institutions in Natural Disaster Management where experts from Sri Lanka, India, and Thailand presented experiences on the subject. Both these activities were helpful in creating awareness on the subject and to document the gaps and constraints in the development process, which led to natural disasters and environmental degradation, and overall impacts in the economy.

NBRO and CHPB in collaboration with the ADPC have introduced already two courses on natural Disaster Management and Community Based Disaster management with the view to increasing the capacity of Government officials, professionals and development workers to face the challenges mentioned above.

Recommendations for effective landslide management

Recommendations in respect of land based entities to be effectively implemented to fruition can only be done with legislative backing and hence may take priority over other recommendations.

- Provision of the necessary legal framework by introduction of legislative enactments in respect of requirements to be fulfilled by all stakeholders including dwellers etc. in all land-based matters, from settlements to large development projects including hydropower projects, infrastructure etc. in landslide vulnerable areas.
- Develop an Early Warning methodology through sector based and area focused probabilistic and deterministic forecasting using rainfall data analysis, historical records, RC data etc.
- The use of Landslide Hazard Zonation Maps produced by NBRO at all levels from grassroots to policy makers to include the entire range of stakeholders.
- As a sequel to above requirement at (1), specific amendments to Building Applications to be affected that would allow Local Authorities to screen the building process in landslide prone risky areas.
- Enhancing of capacity for mitigation not only at national level; but also at local level, including Provincial Councils, Pradeshiya Sabhas etc., where the actual scenarios are handled.
- Awareness creation and mobilization of community support to reduce the usage of high-risk areas.
- Employment of engineering or vegetative practices, or both, as the situation demands, in landslide prone areas, in mitigation of risk.
- Shift from crises management to long-term risk management to ensure sustainability of development initiatives.
- Better co-ordination of all aspects of risk management.
- Demonstrate the effectiveness of mitigation action planning at all levels. Creation of guidelines for implementation of mitigation initiatives in areas to be reconstructed or rehabilitation sites following the disasters.
- Introduction of disaster resistant housing in landslide prone areas.
- Effective regional co-operation and implementation of such recommendations made at various fora.